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VALLEY DEPOSITS IMMEDIATELY EAST OF THE CHANNELED SCABLAND OF WASHINGTON. II

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TRIBUTARY VALLEYS OF THE CLEARWATER AND THE SNAKE ABOVE LEWISTON

The indicated depth of glacial flood water at Lewiston and Clarkston shows that, if the writer's hypothesis be correct, more records of this same character should be found up the Snake and the Clearwater to the crossing of the 1,300-foot contour—and no farther. The writer's study has not yet demonstrated this. There is, however, some more evidence to present.

The lower canyon of Potlatch River, a tributary of the Clearwater, contains a rude, dissected terrace whose frontal edge stands about 30 feet above the valley floor. It is composed of light tan-colored silt and sand, fairly well stratified though with undulatory contacts and some variation in thickness. In pockets and seams, and indistinctly stratified through some of the layers, are multitudes of coarse angular grains of basalt. Scattered sporadically through the silt are angular foreign pebbles and cobbles. In one section there are at least twenty fragments of the granodiorite porphyry, all grouped closely though aligned with the stratification. The largest fragment is 8 inches long. The altitude of the group of fragments is 985 feet A.T. It lies nearly 100 miles up-valley from the scablands.

At the mouth of Asotin Creek, 5 miles south of Clarkston, is a terrace whose surface is 950 feet A.T., 140 feet above the business district of the town of Asotin. The material in the upper part of the terrace is almost wholly coarse black sand, without lenses or strata of silt or fine sand. The material of the coarse sand is largely very angular, unweathered basalt. Its bedding is of the saucer type of current foresets, the laminae dipping toward the Snake. This is close to the southern wall of the creek valley. Traced out into the Snake Valley, the bedding of this continuous deposit, lower in the section, is of long deltaic foresets which dip up the Snake. Still lower and farther out the material is chiefly yellowish silt and sand, though with beds of the coarse black sand.

The deposit lies wholly on the south side of the tributary mouth. The large creek surely has removed much of it, and there may have been, originally, a duplicate of the Tammany Hollow bar here. There is no possibility of deriving all this fresh angular basaltic sand from the Asotin Creek valley. There is plenty of old weathered basalt gravel up the Asotin which should be present in the deposit if the débris came down the creek. There is no possibility that Asotin Creek or Tammany Creek or any of the many other streams with constricting valley mouth bars could have built these forms. The shallow foresets dipping out into the Snake and up the Snake are logical structures for a huge eddy in the up-valley current, an eddy determined by the tributary mouth on the outside of a sharp curve in the course of the Snake.

Farther back up Asotin Creek valley are the characteristic silts, with an unusually large percentage of fresh angular fragments of granite, diorite, porphyritic lava, quartzite, schist, etc. A granite boulder 2 feet in maximum diameter lies at an altitude of about 1,000 feet A.T., at least 250 feet above the Snake.

The mouth of Ten-Mile Canyon, its name indicating its distance above Clarkston, contains a large portion of a gravel bar. It is 225 feet from bottom to top, and the summit is 1,025 feet A.T. It is much gullied, but its original form is still very well preserved. So far as pits and road cuts show, it is composed of foresets which dip back into the tributary valley mouth from the Snake and also dip southward down the northern wall of the tributary valley. Numer-

ous large boulders of weathered basalt lie on the eroded slopes of the bar and are embedded in its gravel, boulders which were torn off the northern shoulder between the tributary and master valleys by the same current which built the deltaic foresets down this northern wall. This current up the Snake swept across the shoulder at an altitude certainly 300 feet above the base of the deposit to which it contributed.

About 8 miles farther up the Snake is the mouth of Couse Canyon. In it lies another one of these extraordinary local gravel deposits. It extends 175 feet from bottom to top, but rests against the sloping northern wall of the valley and nowhere is very thick. But, like the other deposits, it is a definite shoulder built out into the tributary valley. It also contains large boulders of weathered basalt buried in the much finer débris whose basalt content is largely fresh. No structure is exposed. The top of this bar is 975 feet A.T.

The discovery of Couse Canyon bar was made just at the close of the field season. With it came the discovery of a feature as extraordinary as anything yet listed, a feature whose diagnostic value obviously is great. There was no opportunity at this late date, however, to apply it to the many gravel deposits already studied.

The material of this bar is strikingly angular and at first glance appeared to contain no pebbles with rounded shapes. When sought, these shapes were found, though their percentage is very low. But three out of every four pebbles with rounded surfaces turned out to be only chips or splinters or perhaps halves of originally rounded pebbles. The remainder of the outlines are distinctly angular or subangular and sharply truncate the curves of the rounded side.

To check this feature with present Snake River gravels, two nearby bars now swept in flood time were examined—a bar composed chiefly of large cobbles and a bar without cobbles. In the cobble bar, the associated pebbles among the interstices can move only when the cobbles are in transit. They should, therefore, suffer the maximum of pounding by larger fragments which the Snake is capable of affording, except perhaps in rapids. Less than 30 per cent were broken-rounds, and there were almost no angular shapes. In the bar without cobbles, broken-round pebbles (up to $2\frac{1}{2}$ inches in diameter) constituted $12\frac{1}{2}$ per cent of the total. Essentially all else

was rounded. Most of the fractured surfaces on all of these Snake River pebbles have been notably abraded subsequently. In the Couse Canyon bar, most fractured surfaces are ragged and hackly, indicating deposition promptly after the breaking.

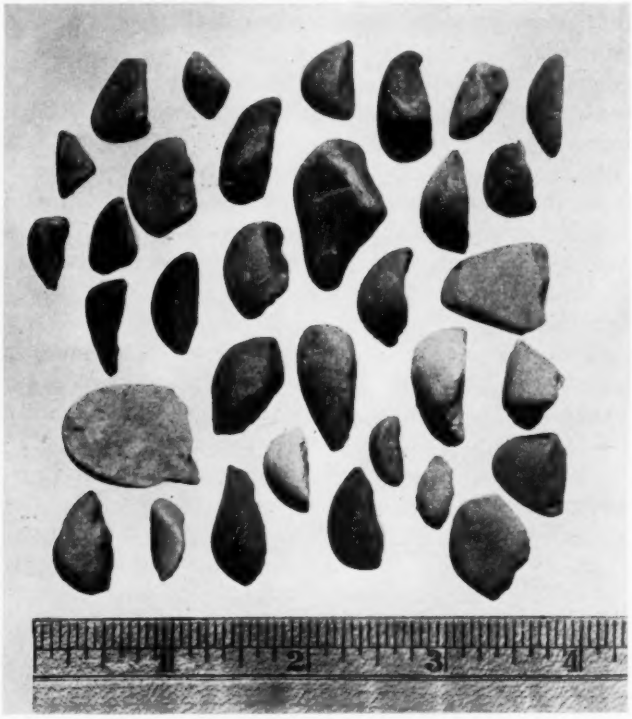

FIG. 4.—Broken-round pebbles from Couse Canyon Bar

Though this was the last gravel deposit investigated in the field study, three "mine-run" collections of angular gravel had already been made—one from the Clarkston semimound, two from the Tammany Hollow bar. These have yielded broken-rounds of identical character. In the Clarkston collection, 1.4 per cent of the pebbles are rounded on all surfaces, 5 per cent are broken-rounds, and 93.6

per cent are completely angular. In the two collections from Tammany Hollow bar, rounded pebbles constitute 0.3 per cent and 1.0 per cent, broken-rounds constitute 3.7 per cent, and 6 per cent, and completely angular forms make up 96 per cent and 93 per cent of the total.

The screening of silt samples taken from Snake River valley and its tributaries has also yielded broken-rounds in 50 per cent of the collections, some samples revealing 5 or 6 such forms on the 1 mm. sieve. Several specimens showed a dull polish on the rounded outlines and a minutely hackly surface on the fractured surfaces.

The data on these valley-mouth heaps of gravel are now nearly all before the reader. The writer believes that these deposits are unique, and that only a unique episode can explain them. Up-valley currents of great depth and great vigor are essential in that explanation. But as through currents, they are utterly impossible. If glacial water backed up the Snake from the scabland rivers, and if it possessed the current indicated, no descending gradient of the valley floor can be held responsible. The gradient must have existed in the *surface* of that flood. The writer, forced by the field evidence to this hypothesis, though warned times without number that he will not be believed, must call for an unparalleled rapidity in the rise of the scabland rivers.

TUCANNON RIVER VALLEY

This tributary to Snake River enters the larger stream from the south less than 4 miles above the entrance of Palouse River from the north. Scabland extends at least that far up the Snake, and the Tucannon therefore is considered as having a separate entrance into the glacial river-channel system. Opening directly toward the great rivers which poured into the Snake from the plateau to the north, this fairly capacious valley would, according to the flood hypothesis, receive a considerable flow back into it. There are great accumulations of gravel along its slopes near and at the mouth, but no valley mouth bar exists. Heavy gravel veneers on the west wall of Tucannon valley at Starbuck, 5 miles south of the Snake, extend up at least to 750 feet A.T. Foreset bedding in the deposit is oriented in various directions. The material is 95 per cent basalt. Non-basalt

pebbles are well rounded, but the basalt pebbles are essentially all angular or subangular.

The southernmost deposit of this scabland gravel in the Tucannon is about 7 miles up from the mouth. It consists of a few feet of

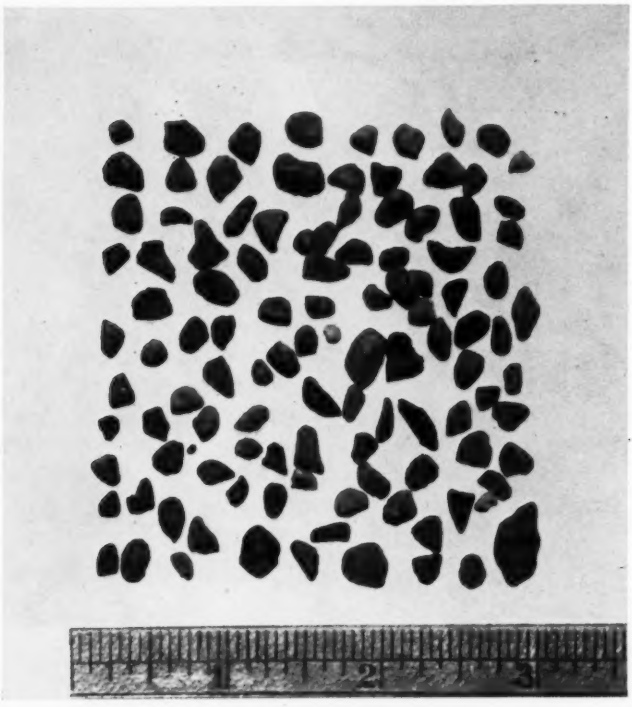

FIG. 5.—Broken-rounds from several samples of the high-level pebbly silts in Snake River valley.

black sand and fine gravel, overlying stratified silts, current-bedded up the Tucannon, and containing a few foreign pebbles. It is low on the valley walls. No gravel deposits in the Tucannon, lying above the valley floor, are known farther up-stream, and in no way can the deposits near the mouth be attributed to the local stream. They are like the great bar deposits on the south side of the Snake opposite

the mouth of the Palouse and a product of the same episode. There is abundant evidence to support this statement farther up the Tucannon.

The valleys of Tucannon River and its tributary, Pataha Creek, have fairly wide floors for many miles above Starbuck. Though the streams have considerable gradients (650 feet in 21 miles along Pataha Creek from Chard to the Snake), the valley floors and the valley slopes carry a heavy silt deposit below 1,300 feet A.T. None

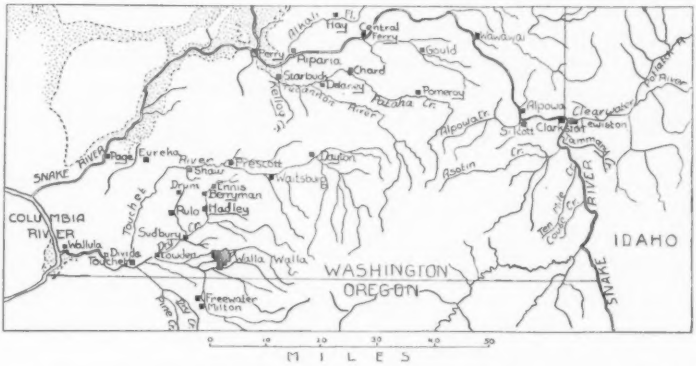

FIG. 6.—Valley deposits immediately east of the channeled scabland of Washington II.

of this silt has been found above that altitude. Fresh highway cuts are numerous from the Snake up to altitudes above 2,100 feet; and this statement is based on a careful examination of most of them, and a sampling of many.[1]

Streams have trenched into this silt until it now constitutes only terrace remnants in most places. The maximum thickness of the silt is certainly more than 50 feet. The best exposures of the silt are in highway cuts at the junction of Pataha Creek and Tucannon

[1] A sample of silt collected at 1,300 feet on the slopes of Tucannon Valley close to the junction of Pataha Creek yielded 11.8 per cent material larger than 1 mm. in diameter. Only one foreign fragment was recognized, a bit of granite. Though the basalt which constitutes this high proportion of non-loessial material is too soft to take steel markings, it is not notably weathered. Little of it is strikingly angular though a few chiplike forms occur. The particles do not have the crumblike shapes that have been found repeatedly for basalt particles in basal portions of the loess.

River. Here the upper surface of the fill is 140 feet above Pataha Creek, 1,020 feet A.T. It lies mostly in the upstream angle between the two streams. The silt deposit at this junction and in the neighborhood is not the poorly sorted or unsorted material which is common on higher slopes. Its stratification is irregular, with many lenses, with irregular contacts, and therefore with variations in thickness almost universal; but the sorting is good. In a 15-foot section, there are ten repetitions of a sequence of fine gravel or coarse sand below light-colored sand which grades upward into tan- or buff-colored silt. The fine gravel is far from clean; perhaps 10 per cent of its volume is silt. Some rhythm in the sedimentation is clearly recorded. But the silt and sand is a deposit of glacial waters, or a derivative of such deposits, for small fragments of non-basalt occur in the fine gravel and a few cobbles of foreign rock are embedded in it. The entire Tucannon drainage comes from the basalt. A little above 1,300 feet, the loessial material on the steep slope above Delaney contains pockets of fresh basaltic particles. There are no foreign fragments here, but they are common about 100 feet lower down this slope.

Many unweathered boulders of various kinds of foreign rock have been brought to light by road grading, most of them from shallow cuts. One fragment of the granodiorite porphyry, 2 feet in maximum diameter, lies in Pataha Creek valley at 1,085 feet A.T., 17 miles upstream from the Snake, and more than 500 feet above it.

The silt terraces are less pronounced eastward up Pataha, and they disappear near Chard, the whole valley floor being covered by the deposit. Here the material is but little sorted and is charged with pebbles and minute sharp bits of fresh basalt and foreign rocks.[1] The highest trace of glacial waters found in Pataha Creek valley was a cobble of granite a little east of Chard and nearly 1,300

[1] Eighteen per cent of the sample from Chard is stopped by the 1 mm. sieve. Nineteen per cent is stopped only by the finest sieve (0.074 mm.), and 35 per cent passes all sieves. Most of the larger fragments on the coarsest sieve are non-basalt and therefore foreign to this valley. To get here they must have traveled 21 miles up the Tucannon and Pataha valleys. The finer material on this sieve is almost all basalt, very angular and largely of fresh material. Knifelike edges of the chips will take a steel streak. The proportion of quartz in the coarser sieves rises from a few grains on the 0.71 mm. sieve to 50 per cent on the 0.177 mm.

feet A.T. No silt was recognized here or farther east along the highway for 35 miles. But the divide between Pataha Creek and Alpowa Creek is crossed in this distance and, descending to 1,300 again, the silts and erratic boulders of Alpowa Creek valley are encountered.

A tributary valley entering the Tucannon from the south, a little above the junction of Pataha Creek, carries the silts up at least to 1,225 feet A.T., where they constitute terrace fragments. At the junction of this tributary, the silt is 40 feet thick and the terraces are well marked. Fragments of foreign rock occur in the silt at 1,225 feet, a mile north of New Hope.[1]

Two north-flowing tributaries to the Tucannon, Kellogg Creek and Smith Hollow, enter the main valley below the junction of Pataha Creek. In the first named, a section 20 feet high occurs at about 1,150 feet A.T. The lower 5 feet is old stream rubble and gravel. The upper 15 feet is of silt or rearranged loess, showing almost no stratification but containing seams and pockets of the fine black gravel or coarse sand.[2]

In Smith Hollow, plenty of the pebbly silt is exposed in a section in the valley floor at 1,140 feet A.T.[3] Foreign pebbles were found

[1] The description for the silt at Chard might be copied verbatim for this sample except for percentages. Twenty-three per cent of this silt remains on the 1 mm. sieve, 34 per cent passes all sieves, and 18 per cent is stopped only by the 0.074 mm. sieve. The following tabulation shows the abundance of quartz grains in the coarser grades.

0.50 mm.—1.6% of total sample—20% quartz—0.32% of total is quartz
0.35 mm.—4.0% of total sample—30% quartz—1.2% of total is quartz
0.25 mm.—4.7% of total sample—50% quartz—2.35% of total is quartz
0.177 mm.—3.8% of total sample—60% quartz—3.38% of total is quartz

In these four sieve samples, more than 6 per cent of the total collection is composed of quartz grains larger than any found in the local loess.

[2] In a sample taken from one of these pockets, only two foreign fragments were found on the 1 mm. sieve, both quartzite. Much of the basalt is in sharp angular pieces whose edges will take marks from a knife blade. Associated with this unweathered basalt are a few pellets of friable weathered basalt, readily crushed in the tweezers. On the 0.71 mm. sieve several grains of quartz were found which contain partially embedded flakes of biotite. Eighty-six per cent of the sample passes all sieves.

[3] Thirteen per cent of the sample from this place was stopped by the 1 mm. sieve, 20 per cent passed all but the 0.074 mm. sieve, and 52 per cent passed all sieves. Foreign material on the 1 mm. sieve consists of quartzite, quartz-muscovite schist, feldspar, and quartz. The curious mixture of much-weathered basalt and unweathered basalt, repeatedly noted, is found here also. The sharpest edges of some of these particles are hard enough to take steel marks, yet the sample collected was only 3 or 4 feet below the surface on a gentle slope.

in the wash material along a road up the side of the valley here to 1,320 feet A.T. The highest erratic was a fresh, coarse-grained granite. Above that level there is only loess and basalt to the summit of the divide.

It is 35 miles across the divide on the east between silts and erratics in Pataha and Alpowa valleys, yet the upper limit is the same in both. This is because the glacial waters which reached back in each came from the same place, the entrance of the scabland flood into the Snake. It is only 12 miles across the divide to the west between silts in Tucannon drainage and in Touchet River valley, a tributary to the Walla Walla; but silts in the Walla Walla nowhere are known within 200 feet of the altitude reached in the Tucannon and Snake drainage. The reason is precisely the same as for the descending series of upper limits in Kamiache, Cottonwood, Lancaster, Rebel Flat, Union Flat, Willow, and Alkali valleys—the descending surfaces of the great rivers.

It should now be clear that basalt grains are abundant in the pebbly silt (reworked loess) up to 1,300 feet A.T. in the Snake River drainage east of the scabland. It should also be clear from the almost universal presence of varied foreign débris that the reworking of the loess and the introduction of the high content of basalt grains was done by glacial water. Almost every sample has yielded essentially unweathered sharp-edged particles of basalt intimately associated with much-weathered pebbles or crumbs of the same rock. The relative proportions of fresh and decayed basalt, however, vary notably. The shapes of the fresh and but little-altered particles are extraordinary. The chips and splinters do not seem referable to abrasion by either streams or glaciers. Vigorous percussion would yield these shapes, as it would produce the broken-round pebbles found in 50 per cent of the silt samples and in several samples of bar gravels. The writer's explanation incorporates this idea of percussion, deriving the basaltic débris from local slopes swept by the rush of glacial backwater. Some of this débris was already well weathered, and when fragmented did not yield the riven shapes.

There are two other possible explanations for these basaltic particles in the silt: (1) they may be the product of local weathering; and (2) they may have been carried back up the Snake from the scablands. The first fails to agree with the field evidence in several vital points and is rejected. The second demands some mechanism for that transportation many tens of miles up the valley lengths and many hundreds of feet up the valley slopes. The only mechanism which seems feasible is berg-ice. Yet the definite berg deposits of the region do not contain basalt. The ice moved so short a distant over on to the basalt plateau

that little, if any, of this material is to be expected. The foreign boulders and cobbles and the larger foreign pebbles in the silt samples were undoubtedly carried by floating ice, but the presence of the basalt does not seem satisfactorily explained by this procedure.

The writer is not yet satisfied with his explanation. There are two items of the field evidence that do not seem to harmonize with it: (*a*) the abundance of very angular quartz grains that obviously did not come from either loess or basalt, and (*b*) the thorough dissemination of coarse particles through the unstratified phases of the silt. An attempt to understand this latter item is outlined in the next few paragraphs.

A sample block of the pebbly silt, several pounds in weight, mixed with twice its volume of water, was stirred vigorously to get it all in suspension, and was then allowed to settle. The coarser particles settled first. Only the finer sand was found mingled with the silt. Several repetitions of this experiment, with decreasing amounts of water, gave the same result so long as the material was sufficiently liquid to take a plane upper surface when the current ceased. To keep the coarser particles suspended in the fine, and thus to duplicate the intimate mixture of all sizes in the original sample, it was necessary to so reduce the quantity of water that the material was a mud sufficiently thick to hold irregularities of its upper surface when stirring ceased. The pebbly, gritty silt of these valleys east of channeled scabland is apparently a mud-flow.

The mechanism of a mud-flow seems utterly at variance with any picture one may devise for the action of glacial water in these valleys. The mantle-like character of the deposit on valley slopes suggests at once the alternative that this intermingling of coarse and fine material is the product of soil creep and is not an original structure at all. But before one concludes that the matter is disposed of by this suggestion, he must explain the thick deposits of pebbly silt on the very gentle slopes of valley flats and even on hilltops, and must account for the undisturbed stratification of clean, fine sand both above and below the problematical silt in some sections. Furthermore, this alternative hypothesis must start with the fact that both erratic particles and sharply angular unweathered basalt particles lay on all these slopes before the postulated soil creep could mingle with the loess. It therefore offers no escape from the idea of a glacial flooding.

Experimental production of creep in the sample material has not been successful. The quantity worked with was so limited that the influence of friction on sides and bottom of a trough extended throughout the mass. A duplication of the internal stresses involved in creep was impossible, and what really was secured was a sliding. Yet with as little jarring as possible sliding in both wet and dry material promptly produced a concentration of the coarser particles in the bottom portion of the sample.

Reverting again to the writer's hypothesis, we may ask how an up-valley surge can produce the mud-flow structure of this pebbly silt. The valleys cer-

tainly were not filled with mud to the upper limits of the turbid glacial water. The silt (reworked loess) and probably the basaltic chips came from the local slopes as the water rose; only the erratic material surely had to come in with the glacial flood, and floating ice can be called on for this.

The mud mixture must, apparently, be considered a product of the agitated marginal water of the rising flood, left in the deepening water with little further disturbance. Some incipient assortment may record a little reworking, but further additions to the deposit apparently would be sorted, and pebbly silt above the stratified material seems to be debarred unless local subaqueous slumping could produce it. It seems certain that if the pebbly silt and the gravel deposits on the valley bottoms are of the same episode, the silt could not have been deposited at the maximum flooding or during recession of the water; else it would overlie the gravel.

The foregoing suggestions are very sketchy. There is no internal evidence in the characteristics of the pebbly silt to support the flood hypothesis. The most that can be said is that the silt is a product of glacial water, that battering of basalt occurred somewhere to make the included coarse, angular grains, and that the conditions of its deposition were extraordinary. The problem of its origin probably will not be solved by consideration of its characteristics alone; the silt must be studied in the light of the other extraordinary deposits of the region.

WALLA WALLA VALLEY

The main current of the glacial flood across the scablands, after entering the canyon of the Snake, followed it down toward the Columbia. About 35 miles below the mouth of the Palouse, Snake River passes to a relatively down-warped tract in which the canyon walls disappear. In this tract, the Snake joins the Columbia. Like all structural valleys with adequate outlet along the course of the glacial rivers, it is an excellent place to test the hypothesis of great volume. Without that volume there can be no high upper limit of silts and berg-borne erratic boulders, for structural valleys on the Columbia Plateau in Washington have not suffered any considerable deepening by erosion. They are today essentially only the original down folds. The hypothesis of several different epochs of great valley-deepening since the upper bars or silts or scabland were made is obviously inapplicable to a structural valley.

Flooding by glacial water occurred in this structural basin, spreading out in a huge pond 75 miles long. A large part of the Walla Walla drainage area lies in the depression; and glacial water extends eastward up the Walla Walla from the Columbia, reaching in one

place within 12 miles of the Tucannon backwater. Due to the low altitude of the district and the lack of notable canyons in it, most of the divides of the Walla Walla basin were submerged by the wide sheet of water. Hundreds of observations in all parts of this drainage area show that the glacial water reached up to, but nowhere above, 1,100 feet A.T. Over the site of Walla Walla city, close to the eastern limit of the flooding, it was 175 feet deep; and at the junction of Touchet River, a major tributary of the Walla Walla, it was 650 feet deep. Since the drainage of the Walla Walla system is wholly from loess and basalt, any other material in the sediments must be a contribution from the Snake or the Columbia valleys.

EUREKA FLAT

A curious feature of the loessial hills which diversify the surface of the Walla Walla region is their elongated linear shapes, trending approximately N. 20° E., and their close spacing. Among these linear hills between Walla Walla River and the Snake is an equally curious elongated flat, several miles wide and nearly 30 miles long, subparallel with the Snake and trending about 40° east of north. The surface of this flat rises gradually from the southwest about 17 feet per mile to the northern end, from which one can see the mouth of the Palouse a thousand feet lower and 6 or 7 miles away.

Whatever the origin of these peculiar topographic features in the loessial cover of the basalt, they control the minor horizontal irregularities of the upper limit of silt and erratics. The topographic expression of this low part of the Columbia Plateau, therefore, antedates the flooding.

The lower part of Eureka Flat was inundated by water escaping directly out of the Snake. The glacial silt 3 miles north of the town of Eureka is more than 20 feet thick. It is composed chiefly of reworked loess, horizontally stratified, but contains many layers of fine, light-colored sand and many pockets and strata of coarse basalt sand, the grains angular and unweathered. The evidence of glacial origin is found in hundreds of grains, pebbles, and cobbles, and in a few boulders of a variety of foreign materials. Some of the cobbles and boulders bear good striae. There are a very few thin seams of gravel, in which foreign débris is prominent. Similar sections occur

both east and west of the town. But though the flat continues for 15 miles farther northeast, rising from 1,050 feet (the highest silt) to 1,500 feet at the northern end, nothing except loess and basalt were found on its floor.

TOUCHET VALLEY

The headwater creeks of Touchet River flow northward from the northern spur of the Blue Mountains, uniting near Dayton and Huntsville to flow westward for about 30 miles to the eastern margin of Eureka Flat. The river, here 200 feet lower than the flat, turns southward along the contact of Eureka Flat on the west and the close-set linear hills on the east to enter Walla Walla River about 20 miles farther downstream.

The characteristic records of the glacial flooding occur in well-marked terraces for 12 miles along the east-west stretch, extending as far up as Prescott (1,038 feet A.T.). But east of a point about 2 miles beyond Prescott, the road cuts show only basalt and loess. The loess is reddish or yellowish in color, intimately cut by seams of lime and in some places full of closely spaced nodules of lime-cemented loess.

Sections in the Touchet valley terraces show a gray silt full of tiny black basalt grains and bits of foreign rock. Its thickness at Shaw, about 2 miles east of the margin of Eureka Flat, is nearly 80 feet, the height of the terrace above the river. At Prescott, which is essentially the upstream limit of the silt, the terrace itself constitutes the highest of the deposit, about 1,050 feet A.T. At Shaw, however, the terrace top is 890 feet[1], and the silt extends up the lower slopes as a mantle to 1,020 feet, where the highest occurrence of fresh basalt grains in the loessial débris was found.[2] Two foreign

[1] Seventy-one per cent of the sample from this terrace has the texture of loess. Six per cent is of particles too large to pass the 1 mm. sieve. In the coarser material angular basalt is dominant, some of it fresh and some weathered. Particles of granite, vein quartz, and quartzite are associated with the local rock débris. Quartz constitutes 5 per cent of the material on the 0.71 mm. sieve, 10 per cent on the 0.5 mm. sieve, 25 per cent on 0.35 mm. sieve, and 50 per cent each on the 0.25 and 0.177 mm. sieves. Very little of this quartz shows worn surfaces. A few cleavage fragments of feldspar were recognized on the 0.5 mm. sieve. In essentially all respects, this Touchet Valley silt is like that described for Snake Valley.

[2] Only 1 per cent of the sample taken here was stopped by the 1 mm. sieve, and 74 per cent passed all sieves or was stopped only by the finest one. The only foreign ma-

pebbles were found at 1,090 feet A.T., 4 feet down in the dust and loose loess.

In its southwestern course along the margin of Eureka Flat, Touchet valley was completely submerged by the glacial water, the silt deposits lying back on the adjacent upland. As far down the valley as Johnson's Bridge (6 miles upstream from Walla Walla River) almost every cut in unconsolidated material exposes unstratified silt charged with pockets and disseminated particles of rock, basalt greatly predominant. Near Johnson's Bridge are two splendid exposures of the silt, each nearly 100 feet high. In one the lower 50 feet is composed of brown silt or fine sand, rather massive, well sorted, and so coherent that it forms cliffs. There are a very few pebbles of foreign material in it. No pockets or lenses of the coarse basaltic sand were found, though there are a few lenses of angular basaltic pebbles and cobbles. The upper 50 feet consists of a weaker silt which does not maintain cliffs, which is more gray in color, and which has plenty of lenses and pockets of tiny pebbles and coarse sand grains.[1] A few cobbles and boulders of non-basalt

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terial consisted of the abundant quartz grains, some large thick mica cleavage fragments, and one unworn cleavage bit of feldspar. Some angular grains of quartz on the 1 mm. sieve contain mica flakes partially embedded in them. The dominant basalt on the coarser sieves is subangular to subrounded. Much of the quartz is subrounded. Both fresh and unweathered basalt are present, some bits with knifelike edges that take a steel mark.

[1] Fourteen per cent of the lowest of this pebbly silt is stopped by the 1 mm. sieve; from 4.6 per cent to 6.8 per cent remains on each of the next seven sieves; and only 44.4 per cent passes the 0.074 mm. sieve or is stopped by it. The coarsest grade contains fully 10 per cent of foreign material, and it is in as small pieces as the 90 per cent of basalt on this sieve. Most of the basalt is wholly unweathered and exceptionally angular. A few broken-rounds occur in this sample, mostly of foreign rock, which must have been rounded, and probably were broken also, before being carried back into the Walla Walla depression. The proportion of quartz on the six coarser sieves increases from a few grains on the 1 mm. sieve to 50 per cent or 60 per cent on the 0.177 mm. sieve.

Whereas splintering and chipping of local basalt was apparently possible in the back-rush up Snake River valley, that procedure does not seem probable here. There was no opportunity for production of such a current here, nor were there numerous basalt outcrops. The very sharply angular basalt of the Touchet valley silt seems best explained as a derivation of the scablands themselves. It is difficult, however, to account for their transportation here. Even though some basalt might be included in berg-ice, it would hardly be limited to these grade sizes and these shapes, and it certainly would

are scattered sporadically through the silt. There is no really good stratification in either member.

Another section, half a mile farther upstream, shows much the same things. Light-brown, rather massive sand and silt underlies brownish and grayish stratified sand and silt. Pockets and lenses of coarse sand and small pebbles are rare in the lower brownish member but common in the upper member. The stratification is irregular and undulatory in detail and in the large. It seems to record different times when the water here became more muddy and then cleared up somewhat. But how are we to explain the currents recorded by the coarse-textured basaltic sand containing particles of foreign rock? And how explain the pocket form of much of this aggregate? Some of these are as thick as they are wide; none are elongated as thin strata. They might be explained as small masses dropped from berg-ice; but lenses of such material, indubitably so, are present in other sections in the Walla Walla valley and have such strikingly different composition that this explanation apparently must be rejected. Whatever the details of a final explanation may be, it seems obvious that exceptionally turbulent and excessively turbid water must be admitted.

Sections in the silt of Touchet valley south of Johnson's Bridge show a great deal of stratification; and the extensive silt terraces out in the open Walla Walla valley, shortly to be described, possess a very uniform and regular stratification.

The area between Touchet River and Walla Walla River, approximately 15 miles wide, slopes southward toward the larger stream. The divide runs subparallel with the Touchet, 300 to 500 feet above it, and only about 2 miles south of it. Several minor valleys in this gentle southern slope will now be examined.

DRUM-RULO VALLEY

The up-valley limit of silt in this unnamed drainage way is at Drum station, 1,045 feet A.T. It has all the familiar characteristics so frequently recited. But at 1,100 feet, three-fourths of a mile north of Drum, an excellent new section yielded nothing but gray loess with

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not constitute 90 per cent of berg contributions. The finer foreign material in these silts seems too thoroughly intermingled to have dropped directly from floating ice.

nodular lumps.[1] Southward from Drum, the little valley contains terraces, the pebbly silt being recognizable in dozens of road cuts. South of Thiel, this silt shows a stratification of irregular and undulatory beds, but the sorting of sand from silt is very imperfect.

ENNIS-BERRYMAN-HADLEY VALLEY

The highest record of glacial water in this minor drainage line was found on the valley bottom at 1,090 feet A.T., four-fifths of a mile north of Ennis station. The evidence consists of a few pockets of pebbles and grains containing foreign material.[2] At 1,100 feet and above, along this valley way, only clean gray laminated loess is exposed in the road cuts. Lest one think that these pebbly silts on valley slopes might be outcrops of a formation between the basalt and the true loess, it should be noted that half a mile north of Ennis, at 1,070 feet A.T., a cut shows nodular loess beneath unstratified gray silt with foreign pebbles and bits of bright basalt. Farther along this cut in the valley slope, the silt disappears and the loess

[1] Three samples were collected in this vicinity—one in the highest exposure of the pebbly silt at 1,045 feet A.T., one a mile down the valley at 1,020 feet A.T., and one of the undisturbed loess three-fourths of a mile up the valley at 1,100 feet A.T. Coarse material is most abundant in the lowest sample. The loess itself has no coarse material, and the contrast between its composition and that of the pebbly silt samples is the universal contrast throughout all the country immediately east of scabland. Foreign material in the pebbly silt includes granite, gneiss, quartzite, diorite, mica schist, and vein quartz. Many quartz grains on the coarser sieves have embedded portions of crystals of hornblende, mica, and feldspar.

[2] A sample taken at 1,090 feet A.T. has 3 per cent of its weight stopped by the 1 mm. sieve, while 78 per cent either passes all sieves or is stopped only by the finest. Another sample, taken a quarter of a mile farther down the valley, contains 10.5 per cent of material too coarse to pass the 1 mm. sieve, while 65 per cent is stopped only by the 0.074 mm. sieve or passes that. This parallels the result obtained in a similar set of samples in the Drum-Rulo-Thiel valley. Since the glacial silt of these valleys is not sorted and has pockets and seams of coarser material, different samples from any one place should not be expected to agree very closely. Collection was guided in all cases, however, by the justifiable desire to have the anomalous composition most strikingly brought out. These analyses therefore show the maximum amount of coarse material in each place. It seems fair to conclude that there is less of it in the re-worked loess at the upper limit of these narrow valleys. The sharp angular bits of basalt, common in these valleys, are well above the top of the basalt formation, the valleys being wholly in the loess. Like the foreign débris, these innumerable bits of basalt have been carried up the valleys. There is plenty of fresh material in every one of the several samples taken. There has been little, if any, weathering or erosion since the deposits were made.

constitutes the entire exposure. The silt, therefore, lies in a valley in the loess.

An instructive section a mile south of Berryman, at about 950 feet A.T., shows 15 feet of unconsolidated material above basalt. The uppermost 3 feet or so is brown soil, probably in large part a wash deposit from neighboring slopes. Below this is buff-to-brown loessial material, unindurated, containing reddish streaks and patches that are not far from horizontal. This buff-to-brown material contains scattered sharp grains of basalt and foreign rock. One seam especially well charged with rock bits is almost a coarse sand, 3 to 5 inches thick and several feet long. Below the pebbly brownish silt or loess is reddish nodular loess to the underlying basalt. Closely spaced, irregular, intersecting lime seams are especially prominent in it. There is some calcareous infiltration in the pebbly silt—a rare thing.

SPRING VALLEY

Terraces about 25 feet high, composed of the glacial silt, occur in the lower part of this valley, their surface about 920 feet A.T. along the road in section 17. A stream-cut bank here shows pebbly silt, loess, and basalt, though not overlying each other in vertical sequence. The loess is dark reddish brown, dense, hard, and highly calcareous. It contains numerous irregular pebble-sized fragments of weathered basalt, but no foreign material. The angularity is of a quite different type from that possessed by the fresh basalt in the glacial silt. The rock has been crumbled to make these pieces, and the surfaces of the fragments are much pitted; while the fresh basalt particles so frequently mentioned have been sharply and cleanly broken as though by percussion. The adjacent silt is unstratified, distinctly grayish, sandy, and friable. Numerous pebbles of quartzite, granite, etc., are associated with the particles of unweathered basalt.[1] A granite boulder lies in the stream bed near this section.

[1] The contrast in the quartz content of the two samples is worthy of emphasis. The loess yielded a few grains of quartz on the 0.5 and 0.35 mm. sieves, about 1 per cent on the 0.25 and 3 per cent to 6 per cent on the 0.177 mm. sieves. The silt adjacent to this loess yielded numerous quartz grains on the 1 mm. and the 0.71 mm. sieves, 10 per cent on the 0.5 mm., 40 per cent on the 0.35 mm., and 50 per cent on the 0.25 and 0.177 mm. sieves. This notable difference, repeatedly found in other samples also, indicates introduction of the large quartz grains with the glacial water. But the sum of all material on these six sieves was only 5.9 per cent of the total sample, and probably not more than 2 per cent of the flood silt consists of such introduced quartz.

On the divide between Spring Valley and Dry Creek to the south, half a mile from the section, the same pebbly silt occurs at 1,050 feet A.T.[1]

DRY CREEK

The main valley of this stream describes an arc of 120° about the northern environs of Walla Walla, its radius approximately 6 miles long, and that city lying at the center. Dry Creek receives the drainage of the three minor valleys just described. Being lower and more capacious, it has more of the silt deposited by the glacial flooding. No sections were available on the floor or lower slopes in the vicinity of the 1,000 and 1,100 foot contour crossings; but where the valley floor is about 900 feet, the slopes on both sides carry the pebbly silt, up at least to 990 feet A.T. on the south[2] and to 1,050 feet on the north. A terrace fragment constituting a low mound on the valley floor at 950 feet shows unstratified silt charged with tiny pebbles and large sand grains of angular fresh basalt. Associated with them are a few fragments of non-basaltic rock.

The deposit is much thicker a few miles farther down the valley. Near Paul School, a cut 27 feet deep is wholly in the silt. Layers of sand and silt alternate. Sharp contacts are more common than gradations. The bedding is horizontal as a whole but has many minor undulations. Few beds are more than 6 inches thick. Many layers of silt are clean and well sorted; others are highly charged with coarse, angular, black basalt grains. There are pockets of basaltic sand, some clean washed, others with a matrix of the silt. There are lenses of angular basalt gravel with many foreign pebbles.

From Paul School down Dry Creek valley, the silt deposit is so heavy that nothing else shows. The present creek flat has been reexcavated from an almost complete fill that was 50 feet or more in

[1] No pebbles of foreign rock were found in this sample. But the presence on the coarser sieves of abundant basalt, some of it angular and nearly fresh, some weathered and crumbling, and of quartz grains which reach a maximum of 50 per cent on the 0.177 mm. sieve indicate the action of glacial water. Furthermore, a cobble of the granodiorite porphyry was found at this altitude on the slope.

[2] Of this sample, 11.6 per cent was stopped by the 1 mm. sieve. It contained particles of mica schist, granite, quartz, feldspar, quartzite, and mica. The mica occurs in large, thick pieces, not in thin flakes. Some of the quartz grains have mica partially embedded in them. The proportion of quartz increases to 50 per cent on the 0.177 mm. sieve. Twenty per cent of the sample passed all sieves, 22 per cent was stopped by the 0.074 mm. sieve, and 27 per cent by the 0.104 mm. sieve.

depth. The low divide between Dry Creek and Mud Creek to the south is entirely covered with the silt. The highest sections here are 950 feet and show only the silt. Indeed, this divide is a dissected silt plain, the summits still holding flattish surfaces, a feature wholly lacking in the loessial hills above 1,100 feet A.T. to the north and to the east.

One section on this divide, near Sudbury, reveals a lens several feet long and a foot thick, very highly charged with angular foreign pebbles. Many of these fragments are well striated on different sides, the marks crossing each other in the fashion typical of glacial striae. No basalt was found in the débris. This lens certainly is not of the category of pockets and lenses dominated by sharp angular basalt grains. It is underlain by well-washed fine sand and overlain by pebbly silt. Both contacts are very sharp.[1]

The lens of coarse non-basaltic débris is interpretable only as a mass of till. Associated small boulders in this and nearby sections tell the same fact: that there was abundant floating glacial ice in the water when the heavy silt mantle was deposited. Indeed, all the coarser foreign débris back in all valleys described in this paper must have been similarly transported. But in almost all cases, the foreign material and the sharp pieces of basalt were mixed thoroughly with the silt before coming to rest. For this mingling there must have been some transportation after release of the foreign material from the ice. And there must have been some method of transportation, other than floating ice, to distribute the broken fresh basalt particles so widely and so high on the pre-existing loessial slopes.

[1] Of the sample from the lens, 77.3 per cent was stopped by the 1 mm. sieve. In all this material, not one particle that could be referred to Columbia basalt was found. Only one holocrystalline fragment was found, a granite. The material appears to consist essentially of slate, argillite, and quartzite. Quartz grains range from 30 per cent on the 0.71 mm. sieve to 50 per cent on the 0.25 mm. sieve. No basalt was found in any of these grades. The fine product consists of 3.8 per cent stopped by the 0.074 mm. sieve and 9.8 per cent passing that sieve. Both the silt immediately below and that directly above the lens are low in percentage of pebbles and coarse grains. Their coarser grades all contain basalt particles. The quartz content on the 0.25 mm. sieve is 40 per cent in the silt above the lens and 60 per cent in that below. On the 0.177 mm. sieve it is 50 per cent and 70 per cent, respectively. Fifty-eight per cent of the upper silt and 69 per cent of the lower are stopped by the 0.074 mm. sieve or pass this sieve.

VICINITY OF WALLA WALLA CITY

Before examining the great silt filling in the central part of the Walla Walla valley, the eastern and southern margins will be considered. The city of Walla Walla is only a few miles from the eastern limit of the large structural down-warp. A pronounced upwarp, constituting a northern spur of the Blue Mountains, rises to summits nearly 4,000 feet above the city, about 17 miles to the east. Numerous creeks flow down the western slope, some to Touchet River, some to Dry Creek, and some to Walla Walla River. Mill Creek, the northernmost and largest of those entering Walla Walla River, has built a large fan in the eastern part of the depression, on which it divides into several distributaries. The head of this fan is about 1,400 feet A.T., and it descends westward about 80 feet to the mile. Walla Walla is built on this fan, altitudes in the city ranging from 900 feet in the west to 1,050 feet in the east.

The glacial pebbly silts with foreign rock fragments overlie the lower part of this fan, except along the stream ways, and extend eastward to upper limits of about 1,080 feet A.T. A small cobble of the granodiorite porphyry was found at 1,100 feet, about a mile east of the city limits. But farther east, nothing except dust, reddish-brown loess, basalt and basalt gravel have been found on the slopes of the Walla Walla drainage basin.

The relations of the glacial silt and erratics to the Mill Creek fan make it clear (1) that some portions of the fan have not been worked over since the flooding, (2) that the fan in the valley and the canyons on the upwarp long antedate the flood, and (3) that the warping which made the canyons and the fan possible was still earlier. This sequence must not be neglected in evaluating any proposed explanation for the distribution of the silt and erratics in Walla Walla valley.

Another fan, built by the south fork of Walla Walla River, lies in the general region of Milton and Freewater, Oregon. It blends with the Mill Creek fan near Walla Walla. It apparently has been completely worked over since the episode of glacial water, for no traces of the silt deposit were found on it. The region, however, has a record of the episode back in the valley of Dry Creek, Oregon, a tributary entering from the south.

DRY CREEK, OREGON

This narrow valley descends a steep structural slope (the continuation of the Horse Heaven Hills uplift in Washington) to Walla Walla plain, debouching about 3 miles northwest of Freewater. A terrace composed of light-colored silt, about 50 feet high, extends northwest and southeast along the front of the uplift at the mouth of Dry Creek valley. Terrace forms continuing its profiles southward up this valley are recognizable for 2 miles back. In every one of several good exposures in this distance, pebbles of various kinds of foreign rocks were found. All were essentially unaltered by weathering, one was distinctly striated. The tiny pebbles and coarse grains of basalt are abundant. They show some tendency toward a stratiform concentration in places. There are also silt layers and fine sand layers which do not show these particles.[1]

The highest altitude at which this pebbly silt was found is 1,000 feet A.T. The next good cut up the valley is at 1,100 feet A.T. The material here has none of the characteristics of the glacial silt. There is no foreign material; and the contained basalt is weather-fractured débris, mostly in large pieces and obviously derived from local slopes.[2]

PINE CREEK

This drainage way, which is very similar to Dry Creek, debouches from the uplifted tract into the plain about 3 miles farther west. Its valley contains terraces of the silt in its lower 2 miles, the highest being 975 feet A.T. The valley farther up is walled and floored with basalt. One section is 20 feet high, with local stream gravel at the base, and all the rest of massive silt in which are a few

[1] In the sample which was sifted, taken from an altitude of 990 feet A.T., 9 per cent was stopped by the 1 mm. sieve and 50 per cent passed all screens. The largest fragments were of foreign rock. Basalt particles, both fresh and weathered, are present. The shapes of the particles are distinctly angular, though not of the extreme forms described in other samples as chips, splinters, or slivers. Quartz is unusually abundant, amounting to 40 per cent on the 0.5 mm. sieve and 60 per cent on the 0.25 mm. sieve.

[2] This silt taken from the valley floor is simply a mixture of loess and local basalt. There is very little quartz in grades coarser than 0.125 mm. Another sample, taken at 1,150 feet, is of the hill-slope loess. The amount of material stopped on each of the first six sieves ranges from 0.3 to 0.8 per cent. Quartz constitutes 25 per cent of that on the 0.25 mm. sieve but only 10 per cent of that on the 0.177 mm. sieve. Seventy-five per cent of the total either passes all sieves or is stopped only by the finest.

pockets and lenses of coarse sand and pebbles. There are plenty of foreign fragments in these pockets, though the easily recognizable "bright" basaltic débris was not found. Another section, near the upper limit in this valley, has numerous foreign pebbles and imperfect stratification and pockets in which coarse basalt sand is very prominent.[1]

A fragment of the granodiorite porphyry was found on the divide between Dry Creek and Pine Creek at 950 feet A.T. There are numerous other boulders of foreign rock associated with it.

WAYLAND ROAD

A minor gulch utilized by this road up the structural slope, a few miles west of Pine Creek valley, contains terraces of silt up to 925 feet A.T. The material of the terraces is typical in every way. The highest exposure is about 180 feet above the silt terrace that flanks the foot of the uplift. It is impossible to select a hillward contact of this terrace, for the surface of the silt mantle rises gently from the terrace flat up the lower slopes.

BUTLER GRADE

This abandoned road southward up the structural slope, nearly south of the town of Touchet, affords no cuts. But the rain-washed and wind-swept old roadway has much coarse black basalt sand concentrated in the ruts. Most of it is unweathered or but slightly weathered. Three to 5 per cent of this concentrate is composed of tiny fragments of unweathered foreign rocks. This persists up to about 1,000 feet A.T. Here the steep grade disappears across a structural flat, and little wash has occurred. The next steep grade begins a trifle below 1,300 feet. A few foreign pebbles were found here up to 1,425 feet, as far as this traverse was carried. But the finer material of the wash contains no foreign bits, and the basalt sand and fine gravel is distinctly weathered. It seems probable that

[1] In two samples of the silt, one taken at 950 and the other at 975 feet A.T., 12 per cent and 8.6 per cent were stopped by the 1 mm. sieve, while 43.5 per cent and 47.4 per cent passed all sieves. Both contain an increasing percentage of quartz down through the first five sieves, reaching 65 per cent and 50 per cent, respectively, on the 0.25 mm. sieve. Both contain unweathered subangular pebbles of foreign rock and angular particles of basalt, some of which is as hard as fresh rock when tested with a knife blade.

these pebbles were scattered along this road in the same way that the bits of crockery, glass, and iron in the wash were carried here.

VAN SYCLE CANYON

Five or 6 miles farther west is a prominent spur of basalt projecting north from the lower slopes of the Horse Heaven Hills uplift. Its summit, nearly a square mile in area, is 850 feet A.T. Walla Walla River has cut a relatively narrow valley across its northern slope, the bottom of which is 500 feet below this summit. Van Sycle Canyon, eroded along the steeply tilted, perhaps faulted, basalt flows, enters the Walla Walla just west of the prominent spur. The fine glacial silt is deep along the lower part of the stream way from this canyon. It extends westward along the foot of the uplift almost to the entrance of Wallula Gateway, the Columbia's spectacular watergap through the Horse Heaven Hills uplift. On both sides of Walla Walla River it constitutes the only material exposed between the rock-walled Walla Walla trench and the Columbia.

THE WALLA WALLA PLAIN

The large downwarp in which Yakima, Snake, and Walla Walla rivers enter the Columbia has minor structural diversities. One of these is a smaller basin in the Walla Walla drainage area. It extends eastward from the basaltic spur above-noted for 25 miles to the foot of the uplift east of Walla Walla. It is about 15 miles across from north to south. The basalt throughout this tract is below all stream grades. In the city of Walla Walla, it is 500 feet below the surface. The low tract has no loessial hills, yet it is much diversified by hills and valleys and has a maximum local relief of 150 feet in less than a mile. Almost all sections seen in this basin are in stratified silt, sand, and gravel. A very few sections show reddish calcareous loess at the base. The water-laid sediments of this plain show maximum vertical sections of 80–90 feet, and the total thickness probably exceeds 150 feet.

The plain is crossed by a multitude of minor streams. These, with Walla Walla River, have dissected the once continuous fill into its present roughness. In the higher marginal parts of the plain the material is like that in the lower parts of the tributary valleys already described. It is light-colored, sorted sand and silt with irregular and undulatory bedding, with seams and strata of dark, coarse

sand and fine gravel, with scattered erratic débris present in almost every section, with pockets and lenses as well as disseminated tiny pebbles and large grains of unweathered basalt.

The restored surface of the dissected fill descends westward about 25 feet to the mile. This might be considered an aggradational slope if the material were fluviatile and had come from the headwaters of the converging streams. But there is abundant evidence that it was deposited in a body of glacial water reaching back from the Snake and Columbia and submerging the region up to the 1,100-foot contour, 600 feet above the surface of the fill in its western part. The slope therefore may be explained more satisfactorily as due to the pre-silt floor, itself perhaps fluviatile. The Mill Creek fan and South Fork fan may be portions of that floor, higher than the surface of the glacial backwater.

Walla Walla River leaves this aggraded plain by the rock-walled trench at Divide and Reese eroded in the northern slope of the basaltic spur near Van Sycle Canyon. This crooked trench has considerable remnants of the silt and sand deposit in it and therefore, in large part at least, is the pre-silt dischargeway from the basin. The trench is 300 feet deep at Reese.

If this be a correct picture of conditions before the submergence by glacial water, let us attempt to visualize the details of the flooding, assuming any normal cause and any reasonable volume for the Snake and Columbia. The rise of that water first produced reverse flow through the trench, the backwater emerging abruptly near Divide into a basin ten times as wide as the rock-walled valley. This condition would persist while the water in the western part of this basin deepened to at least 300 feet, this figure determined by the highest water-laid deposits in the valley here. Notable back-current might have poured through the trench while the water rose, but it could hardly have persisted across the expanding lake in the basin, nor would there be any more favorable conditions for current back across the flooded Walla Walla plain after the water had risen above the barrier at Divide and Reese. Thick deposits of coarse gravel and coarse sand, foreset up the Walla Walla valley, could hardly be deposited out on the broad floor of this lake 5 miles from the eastern end of the trench.

This sketch has been drawn that the reader may better appraise

the character of the water-laid sediments in the western and lower part of the Walla Walla plain. These sediments will now be described.

A river cliff near Cummings Bridge, half to three-fourths of a mile south of the east end of the trench, shows about 60 feet of sand, gravel, and silt. The section in mid-length of this cliff consists of a few feet of brown sand beneath 20 feet of coarse rubble gravel containing foreign fragments. The gravel and sand interpenetrate with irregular lenses of each in the other. Above the poorly worn gravel is 30 feet of fine brown sand to the top of the section. This sand is distinctly and uniformly stratified into beds 2–4 feet thick.

Traced southward less than 1,000 feet, the upper brown sand goes beneath another gravel bed, which in turn is covered with gray sand and silt. This upper gravel member is black, prevailingly rather fine textured and irregularly bedded. It contains several large boulders. The gray sand and silt above it has undulatory and somewhat irregular stratification.

But if traced northward from mid-length of the section, the brown sand above the rubble gravel goes under gray silt and sand. The black fine gravel of the south end of the section is absent. The contact between the uniformly bedded brown sand below and the irregularly bedded gray sand and silt above is unconformable, and its descent northward finally cuts the brownish sand out of the section, the gray silt and sand resting on the rubble gravel. Its undulatory and irregular bedding conforms generally to the sloping contacts and truncates the nearby horizontal bedding of the brown sand.

Except perhaps for the two brown members, this section records deposition in glacial water or derivation from such deposits. The unconformity, which has a vertical range of about 30 feet in the entire section, may record two different episodes of deposition separated by a time of erosion. It may also be considered a product of cut-and-fill during one depositional episode, if current of sufficient depth and vigor can be shown from other evidences. By the first explanation, the brownish color of the uniformly bedded sand might be weather-staining during the erosional interval. By the second explanation, the sand was brownish when deposited. Uniformity of the color throughout 30 feet of sand, the faintness of the color, and the

complete absence of leaching or of infiltration of lime suggest strongly that weathering *in situ* is not responsible for the color. But whether or not two episodes of deposition are here recorded, one may ask why coarse rubble gravel, containing foreign rock material, should be at this place in Walla Walla valley. It does not show anywhere in the trench to the west or in the wide plain to the east. By what routes could it have come to position?

This gravel might be ascribed to the minor Warm Springs Canyon mouthing here from the uplifted area to the south, though Pine Creek, Dry Creek, and Van Sycle Canyon mouths do not have such deposits and Warm Springs Canyon could not supply quartzite, granite, schist, diorite, etc., unless older glacially derived deposits were being eroded. The nearest source for quantities of little-worn basaltic débris is the upper part of the basalt spur. This is essentially scabland, though not channeled. The nearly bare rock of its broad top is quite unlike any similar basalt spurs or eminences in the region above 1,100 or 1,200 feet A.T. But it is difficult to get this material off the top of the spur and on the upstream side by any normal rise of backwater in Walla Walla valley.

Another section showing considerable gravel is afforded by a pit about a mile south of the town of Touchet and 5 miles east of the section at Cummings Bridge. It is essentially in the middle of the Walla Walla valley here, 2 miles from the nearest elevations which might contain basalt as high as the level of the deposit.

The basal part of the Touchet pit section is a coarse gravel, its pebbles generally subangular, its stratification fairly regular, its composition 99 per cent basalt, its material (native and foreign rock) unstained, and its foresets dipping eastward, up the Walla Walla. There are boulders of silt in this gravel, a foot in diameter and light gray in color.

Above the coarse gravel is 12–15 feet of black fine gravel. Well-sorted, well-stratified lenses of fine brown sand appear in the upper part of this gravel and, above it, this sand constitutes a continuous member of the section. Above the brown sand occurs a few feet of fine gray sand containing abundant coarse basalt grains, poorly arranged in irregular strata. They are not segregated cleanly from the gray sand anywhere. Above this in turn is a few feet of gray silt with the same sprinkling of coarse basalt sand grains. Foreign material

was found everywhere in the section except in the uppermost silt and sand.

The total thickness of the section is 90 feet. The bluff summit here is 150 feet above the river, and the 60 feet of material higher than the section top apparently contains nothing but silt and fine sand. The water-laid deposit in this part of Walla Walla valley seems resolvable into a sequence recording, first, transportation of material eastward up the slope of the plain and, later, a gradual diminution of transporting ability. Glacial water is clearly recorded.

The third section to be examined in this part of the wide valley lies about halfway between the two already described. It is the northwestern margin of the irrigated Gardena tracts, which here break off in 80-foot cliffs descending northward almost vertically to the river.

The sections in these cliffs agree in a very general way with that in the Touchet pit. There is fine black gravel, fine brown sand, and gray silt, all well stratified in the large. The silt is limited to the upper third of the sections. But the brown sand and the black gravel are interbedded, the larger part of the gravel being in the middle, not at the bottom, of the sections. The thicker strata of any kind of sediment are lower down than the thinner strata. There are a few cobbles and large pebbles in the black gravel. Current bedding in this gravel is prominent, the shallow foresets dipping eastward against the slope of the Walla Walla plain. In at least three places, all of them at the base of black gravel members, there is clear evidence of erosion of the upper surface of the underlying fine brown sand, obviously produced by the up-valley current which brought in the black gravel.

The silt which characterizes the upper third of the Gardena cliffs is definitely arranged in strata of very fine gray sand grading up into gray silt. The silt is commonly dense and hard, bending the edge of the tobacco tin into which a sample was scraped. These strata are progressively thinner toward the cliff summits. In one place near the top, there are sixteen strata in 6 feet, the thickest being 12 inches, the thinnest about $1\frac{1}{2}$ inches. All are somewhat irregular in thickness, and the fine sand at the base of each has current laminae. A sharp break everywhere separates the layers. In a few places this silt and fine sand contains coarse black sand, either as scattered

grains or in small lenses. Here and there are pebbles and cobbles of erratic material.

A feature not seen elsewhere in the silt deposits discussed in this paper is a pocket or lens aggregation of small pebbles of gray silt in the varvelike arrangement of silt and fine sand. Apparently a fairly coherent silt already deposited was broken up, transported, and redeposited to produce this structure.

The top of none of these water-laid deposits is much above 550 feet A.T., though on the margins of Walla Walla valley and back in tributary valleys, the upper limits of the glacial silt are 1,100 feet A.T. The basalt walls of the trench at Divide and Reese rise on both sides to a minimum height of about 650 feet, and silt in this trench shows that it was also filled while the silt plain of Walla Walla valley was being deposited.

But the silt in the trench shows no varvelike structures. Through a vertical range of a hundred feet at Reese, it is much more like the silt on the higher margins of Walla Walla valley. There is stratification, though it is irregular and undulatory. There is sorting, though much of the material is not sorted. There is much interbedding of gray sand with gray silt. Pockety aggregates or concentrates of coarse unweathered basaltic sand are present; so are thin fairly continuous strata. But there are no marked gravel members, and there is no clean-washed fine brown sand.

Though stratified gray silt and sand cover the floor of the Walla Walla plain almost as far east as Walla Walla, the Gardena type of varve like bedding in the uppermost part of the section has not been found east of Lowden, 8 or 9 miles from the head of the trench at Divide. It is limited to the western and lower part of the basin. It does not occur higher than the summit of the trench walls at Reese. It is sufficiently different from all other phases of the glacial silt to need a different explanation. Two different views may be entertained.

One is that two different deposits are shown in these sections, the silt with varvelike bedding being the younger. There is unconformity in the Gardena sections, but it occurs at different places between sand and gravel in the lower part of the sections and is not at the base of the varvelike bedding. Nor is there any break between the upper varve-bedded silt and the lower and thicker members of

silt and sand. Instead, there is good gradation and the currents recorded in the lower members appear gradually to have decreased until nothing more than lake-bottom circulation existed when the uppermost silt was laid down. In the Cummings Bridge section, close to the head of the trench, there is a more marked unconformity, which may require a definite episode of exposure and erosion for its explanation. But this necessity is not yet clear; and even if required, it is the lone example of its class in the Walla Walla valley, so far as now known.

The other explanation for the well-bedded sand and silt strata in Gardena Cliffs considers that the whole Walla Walla silt deposit was made in one episode of submergence, and that the differences in character are due both to different location and to changes of conditions in one location. This explanation considers that the deposition of silt was synchronous with scabland-making and that scabland waters were of enormous volume for a relatively short time, though initial and closing stages may have been no greater than ordinary melting would produce.

This explanation is built on the strong evidence for pronounced currents of glacial water flowing back from the Columbia and up the slope of the Walla Walla plain. It requires the rock barrier at Divide and Reese. The postulated succession of conditions is as follows:

1. A preglacial, broad, low Walla Walla valley, structurally determined and drained by a narrow valley or trench eroded into basalt at Divide and Reese.

2. A rapid rise of glacial water in the Columbia and Snake valleys which poured back through the trench and finally over the basalt spur above the top of the trench walls. The up-valley currents could be produced in no other way for, as in all other valleys considered in this paper, the water simply backed up; it never flowed through and out by some other route. The scabland up to 850 on this spur was produced by such up-valley current.

3. Deposition of the rubble gravel near Divide and of the better-stratified, finer, and more-worn gravel in Gardena and Touchet sections. These locations are close to the basalt barrier.

4. Great turbidity and turbulence of this water, recorded by the

pebbly silts with berg-borne débris, persisting back to the margins of the Walla Walla valley and up in many tributaries.

5. Attainment of maximum flooding, cessation of the great turbulence, and maximum deposition of silt and sand. This silt to cover the gravel which was deposited during the time of vigorous backflow. The trench at Divide and Reese to be silted full at this time, but the deeper western part of the Walla Walla valley not to be silted up level with the top of the trench walls.

6. Subsidence of the glacial waters, leaving a local shallow lake east of the silt-covered rock sill and the silt-filled trench through it. The lowest place for discharge of this lake to depend on surface of the silt deposit over the barrier and not to coincide wholly with the course of the preglacial trench. A rock sill therefore holds up the level of the shallow lake.

7. The lower part of the silt-choked trench to be cleaned out fairly rapidly and a tributary to be developed which will erode the silt filling in the upper part of the trench where the outlet fails to follow the old trench.

8. Relatively rapid erosion by this tributary eventually to provide a place lower than the sill, for the Walla Walla lake to discharge.

9. Shifting of the outlet, establishment of drainage entirely along the pre-glacial route, draining of the lake and erosion of the lake beds and the underlying glacial silt, sand, and gravel to the present topography.

This sequence explains the varve-like structures in the lower part of the Walla Walla valley only by assuming that the rainfall which would wash silt and fine sand from the higher levels down into this lingering pool had distinct seasonal or other variations, making the lake very muddy at times and allowing it to become clear in succeeding intervals.

The rock barrier is essential. No other place in the entire region is known where varve structures exist in the silt, nor where such a combination of basin and barrier exists. One difficulty with the explanation is the presence of a few pebbles and cobbles of erratic material in the varve-bedded silt. Perhaps shore ice retransported them, but berg-ice appears more logical and is forbidden at this stage. Another difficulty is that the abandoned outlet channel across

the sill has not yet been found. One unusual feature which supports the explanation is the presence of tiny pebbles of silt in the sandy part of some varves. This may record erosion of glacial silt on slopes above the lake level but below 1,100 feet.

The Walla Walla basin sediments differ from those in Snake valley and elsewhere in another item than the varve bedding. There are no gravel bars constricting valley mouths. By the writer's explanation of scabland and silt, these valley-mouth bars should be formed only where a great current in a main valley passed the mouth of a minor valley. Eddying of deep vigorous currents back into these minor valleys seems the only adequate mechanism for their locations, structure, and topography. Since the Snake Valley east of the scablands contains many striking bars of this sort, a great current along the Snake is necessary; and such deposits in this part of the Snake show foresets, prevailingly up the valley, away from the scabland. But since Walla Walla valley had only a narrow trench to carry back the first of the rising flood and a very wide valley for its higher stages to fill, and since it had no great length to fill with water, there was no opportunity for development of currents of this vigor.

Still another difference between the Walla Walla valley and the Snake valley deposits is to be found in shapes of pebbles. Although pebbles in the silt are common, very few broken-rounds have been found. Since they are common to silt deposits in almost all other valleys examined, some special conditions seem indicated. One item may be the absence of a supply of rounded gravel on the Walla Walla plain when the glacial waters invaded it. Another item may be the absence of large boulders of country basalt to serve as hammers. Another item apparently is the failure of the Walla Walla back-flow to develop adequate currents. The most favorable place in Walla Walla valley for broken-rounds to be made is near the trenched barrier at Divide and Reese, but this feature of pebble shapes had not been discovered when the gravel near this barrier was examined.

SNAKE RIVER VALLEY BETWEEN PAGE AND PERRY

Scabland erosional and depositional forms along this part of the Snake have been briefly described in earlier papers. The upper limit near Perry, at the mouth of Palouse River, is 1,325 feet A.T. This is also the altitude of the bases of loessial scarps here. Thence down the

Snake for 35 miles this upper limit descends to about 1,080 or 1,050 feet, at which altitude glacial waters could overflow the lower bluffs and enter Walla Walla valley.

Backwater tracts are amply recorded by the silts both in Snake River valley above Perry and in Walla Walla valley, and the upper limits in each agree remarkably well with the upper limit in the Snake at each mouthing into scabland. It is of great interest therefore to find that this portion of the Snake between the two great pondings contains *no* silt deposits. There are no silt terraces, or remnants of silt terraces; and no traces of any kind of this material except in the mouths of some tributary canyons that are not detailed here.

It is a remarkable thing that Walla Walla valley should have an almost complete mantle of silt 80–100 feet in maximum exposed thickness and ranging through 650 feet of altitude, a deposit conspicuous in almost every cut 5 feet or more in depth and expressed in the topography almost everywhere, while the adjacent Snake River valley, even deeper than Walla Walla valley, should have no trace of the deposit on slopes, in washes, in terraces, in mantling of the bar gravel or masking of the scabland. It is equally remarkable that the valley of the Snake does contain just such deposits *above* the mouth of the Palouse.

For this striking contrast, the following explanations may be proposed:

1. The silt deposit is older than the scabland. The glacial flood has subsequently swept away all that was deposited in Snake valley between Perry and Page.

2. The silt deposit is older than the scabland; and the erosion produced by a series of episodes of glacial discharge down the silt-free portion of Snake valley, plus interglacial stream erosion, has removed the silt.

3. The silt deposit is the correlative of the scabland and its gravel bars. The scabland is the product of enormous rivers operating during a very short time, geologically.

4. The silt is contemporaneous with scabland, but both are the cumulative result of several glacial episodes.

5. The silt is younger than the scabland but has been removed by subsequent erosion on the slopes and bottom of Snake River valley.

If the silt is older than scabland and if the scabland is a record of enormous glacial torrents, then there is no record of that flood water back in Walla Walla valley or in Snake River valley above Perry. There is also no mechanism provided for the extraordinary features of this silt and its associated gravel. The coincidence of upper limit of scabland and silt in both pondings must be dismissed as coincidence only. The difference in level in the two pondings is left unexplained. The only merit of this explanation is that it is a possible escape from the flood hypothesis.

If the silt is older than scabland and if the scabland is the product of several Pleistocene episodes during which (and during the interglacial intervals separating them) the canyons were deepened a few hundred feet, the continuity of the silt mantle must be a matter of successive overlaps from the later pondings in the deepened valleys. This erosion is impossible in the down-warped Walla Walla basin; hence the higher level of the silts there would be impossible by the proposed explanation. The unweathered condition of the highest silts in each of the two large pondings would be very difficult to explain. The persistence of an extensive mantle on steep slopes at the upper limits would be impossible, for deepening in the wide-open valleys means at least as much widening, probably much more. If there were narrow inner gorges of the required depths in these more flaring valleys, this objection to the explanation would be removed. But no such gorges exist.

If the silt is correlative with the scabland and if the writer's interpretation of scabland, scarps, and gravel deposits is correct, there are no disharmonies in the scheme. Objections to this explanation will be made on a priori grounds, not on the field evidence.

If silt and scabland are correlative but both are the consequence of several Pleistocene epochs, several objections already presented must be met. The highest of the silt deposit should be exceedingly fragmentary instead of a continuous mantle, its basalt grains and foreign pebbles should be distinctly decayed, the different soil horizons should be present in the higher silt where on flats or gentle slopes. These features are not present. Most cuts in the reddish or buff-colored loess of the plateau show good A and B horizons, but no cuts in the silt anywhere in the region have shown them. The remarkable gravel deposits of Snake valley and their remarkable setting and

structure are ignored by this hypothesis. So are the less striking but significant gravel beds in the western part of the Walla Walla plain.

If the silt is younger than scabland, its absence in Snake River valley between Page and Perry must be due to still later erosion. Yet the Snake just above the scablands has the mantle, and there are hundreds of re-entrants between Page and Perry where material of such geologic recency should still be conspicuous. There are flattish uplands above the brink, yet no silt on them. There are broad, deep, and partially inclosed depressions back of the great gravel bars, in which almost no erosion has occurred since the bars were built; yet no silt occupies them.

The writer believes that a fair evaluation of these different hypotheses for the absence of silt deposits in Snake valley between Page and Perry will rule out all but the two which consider the silt as contemporaneous with scabland. A fair consideration of the unique field evidences will carry conviction that scabland-making, silt-deposition, and valley-cutting on the plateau did not extend through several Pleistocene episodes. Many of the original features of scabland and silt are impossible by that view, and their equal freshness at all levels through a noteworthy vertical range debars that view.

CONCLUDING STATEMENT

The greatest known thickness of the poorly stratified and pebble-charged silt and sand is at Johnson's Bridge on Touchet River. The section extends from 550 to 650 feet A.T. The upper limit of the water body was 450 feet above the top of the section. If all this silt was carried in during one short episode of exceedingly turbulent water, 100 feet of silt was suspended in 550 feet of water. Would the increased specific gravity of such muddy water be a factor in the transportational problem afforded by the widely scattered tiny bits of fresh basalt? These particles must come in from the scablands; they cannot be produced in Walla Walla valley (though they may have been so produced in Snake valley).

It may well be asked, also, if this method of silt transportation is supported by all the field evidence. Is the partial sorting and stratification possible by this hypothesis? Is not some kind of rhythmic pulsation in water supply and sediment supply recorded in the common irregular and undulatory strata? One might well be in-

clined to think the stratification impossible by the flood hypothesis, and perhaps the writer's conception should be modified to allow for minor rises during a subsidence from the maximum.

If this be correct, the stratification should be in the upper part of the deposit. Most sections are too shallow to show full thickness; but so far as now known, the stratified phases do not underlie any notable beds of unstratified silt. However, they do not occur close to the upper limits of the deposit. This upper-limit silt seems everywhere to show the minimum of stratification.

Another explanation for the stratification might be modeled on the preferred interpretation for the varve-like silts in Walla Walla valley. Later re-working on the valley floors is possible during subsidence of the flood and perhaps for some time after that. Various gravel bars would have been effective dams for a time. Perhaps irregularities in the surface of the silt deposit itself would have provided short-lived basins in which re-working of wash from adjacent steeper slopes could occur.

The flood hypothesis encounters another objection in the silt lenses occurring in gravel deposits. Such lenses demand cessation of current while they are formed. How rapidly does the finest of this silt subside? Experimentation with silt which passes the 0.074 mm. sieve shows that in a mixture of one part silt to four parts water, half of the silt settled out in 2 minutes after stirring was stopped, three-quarters in 5 minutes, seven-eighths in 9 minutes, and all but about one-fiftieth in 15 minutes. The need for constant turbulence to maintain even the finest of this material in suspension is thus evident. A very brief cessation of current essentially clears the whole water body.

If one discounts or denies the evidences of torrential up-valley currents and considers this record of glacial backwater in more than forty separate valleys as the product of a general ponding, he must then explain the progressively higher altitudes northward from Walla Walla River to Kamiache Creek as the result of subsequent warping. The amount of such required warping is slight for this region, only 800 feet in 100 miles. He must then explain the horizontality of upper limits at widely separated places in the Walla Walla valley system and in Snake valley and its tributaries as due to a lack of differential movement in each of those portions of the

warped surface, though he must have 200 feet of warping in a narrow zone between them. He must next admit that, at the time of ponding, there could be essentially no gradient for the recorded upper surface of the vigorous scabland rivers from Kamiache Creek to Walla Walla River, and he must deny therefore that these river-scoured surfaces were formed as early as the ponding records. The agreement of upper limits of scabland and upper limits of ponds can then be coincidence only.

If he is willing to grant preglacial valleys essentially as now, and scabland contemporaneous with the ponding, but desires to use this conception of warping, the combined Palouse and Snake (where used by glacial streams) had a preglacial descent of about 600 feet in 100 miles, as contrasted with the present descent of 1,400 feet in that distance. On this gradient of 6 feet to the mile the glacial streams must have eroded the scabland.

If, however, while retaining the idea of warping, he prefers to think that the highest scabland and pond records and all of the loessial scarps antedate the canyon-making in the plateau, he must reduce this preglacial gradient of the plateau to something like 3 feet to the mile. In other words, the admittedly recent deformation must be interglacial. And on this gradient (for large volume is debarred by this conception) he must develop the velocities necessary for the erosion of the high scabland and the scarps. The difficulties by any of these combinations are great. And field evidence reviewed in this paper is utterly at variance with them.

The final accepted explanation for channeled scabland must be built on, limited by, and constructed to include, all the field evidence. That such evidence is of extraordinary character is obvious to any geologist. That it is unique should be clear to glacialists and physiographers. The writer is convinced that anyone who attempts to evaluate the evidence must discard the idea that glacial waters here behaved as elsewhere, the only difference being in magnitude of results. He holds that it was a difference in kind of results. The data in this paper constitute a category of facts not known when the flood hypothesis was first proposed. The relations to that hypothesis are to be decided by the reader. The writer asks only that, if his interpretation be rejected, the data herewith presented be organized to make some coherent interpretation.

NEW AREAS OF ALKALINE IGNEOUS ROCKS IN CENTRAL ARKANSAS[1]

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ABSTRACT

Two volcanic necks and a number of sills, recently discovered in central Arkansas, are of considerable interest because of the great thickness of sedimentaries which they intrude, and because of the variety of alkaline rock types found in them. The intrusions cut Pennsylvanian strata, and probably are the result of the same mid-Cretaceous vulcanism which is responsible for the other Arkansan igneous bodies. Diamonds, found in the only other described igneous neck in Arkansas, probably are not present in these newly described intrusions. The presence of these structures may be regarded as only slightly adverse to the possibilities of gas in the general area in which they occur.

INTRODUCTION AND ACKNOWLEDGMENTS

References to the igneous rocks of Arkansas have appeared in geologic literature for more than a century; and owing to the unusual alkaline types and the peculiar mineral associations, particularly at Magnet Cove, these rocks have attracted the world-wide attention of petrographers and mineralogists. In 1906 the discovery, in the peridotite plug of Pike County, of the only known North American occurrence of diamonds *in situ* has lent additional interest to these rocks, and has stimulated some search for other igneous areas, which has not been particularly fruitful.

During the field season of 1927, while making a study of the gas possibilities of the Arkansas Valley area of Arkansas, the attention of Mr. Croneis was called to the designation, on a rough manuscript prepared by Arthur Winslow and E. C. Buchanan (in about 1888), of an igneous rock outcrop on the south bank of the Arkansas River near Morrillton. This general area was visited and four sills were located, one of which is probably the structure previously discovered. Because of the possible bearing of such intrusions on the gas possibilities of the area, some attention was given to the search for other igneous bodies during the rest of the field season. As a result, two volcanic necks and an additional sill were discovered; and

[1] Published by permission of Mr. G. C. Branner, state geologist of Arkansas.

the location of several other probably igneous intrusions was ascertained, although it was impossible to verify their existence.

The Oppello volcanic neck, described on a later page, was first noticed by Mr. W. J. Sadler, of Oppello, who sent a sample of the rock to the state geologist, Mr. G. C. Branner, who considered it a possible igneous breccia. Mr. Sadler was kind enough to take Mr. Croneis to the outcrop (see Fig. 2). As the time available was too limited to make a detailed search for other igneous outcrops some specimens of the Oppello breccia were shown to many of the farmers met during the survey. As a result Mr. J. R. Myers, of Perryville, recognized, in the sample, rock similar to that in an outcrop on his farm, and thus the Brazil Branch neck was discovered. Another outcrop of igneous rock, which we have designated the Perryville sill, was encountered in measuring a section of the Atoka formation between Perryville and Perry. Because of the hit-and-miss methods used in locating these intrusions, it seems very probable that other igneous bodies may be discovered in the same general area. The rock specimens collected during the course of the work were studied petrographically by Mr. Billings, and the problem of their origin was considered jointly.

The writers wish to express their thanks to all of the men previously mentioned, and also to H. L. Anderson and C. D. Robinson for field assistance.

GEOGRAPHIC LOCATION AND PREVIOUS WORK

The principal areas of igneous rock in Arkansas are shown in Figure 1. The Murphreesboro occurrence, according to Miser and Ross,[1] is a complex volcanic neck. The four other areas of major importance—Potash Sulphur Springs, Magnet Cove, Saline County, and Fourche Mountain—have been described by Williams[2] and Washington,[3] and represent deeper-seated intrusions. Several hun-

[1] H. D. Miser, "New Areas of Diamond-Bearing Peridotite in Arkansas," *U.S. Geol. Survey Bull. 540* (1912), pp. 534–46; H. D. Miser and C. S. Ross, "Diamond-Bearing Peridotite in Pike County, Arkansas," *Smithsonian Report for 1923*, pp. 261–72; H. D. Miser and C. S. Ross, "Diamond-Bearing Peridotite in Pike County, Arkansas," *U.S. Geol. Survey Bull. 735* (1922), pp. 279–322.

[2] J. F. Williams, "Igneous Rocks of Arkansas," *Arkansas Geol. Survey, Annual Report, 1890* (1891), Vol. II.

[3] H. S. Washington, "The Foyaite-Ijolite Series of Magnet Cove: A Chemical Study in Differentiation," *Jour. Geol.*, Vol. IX (1901), pp. 607–22, 645–70.

dred small dikes and sills, genetically related to the larger masses, occur in the southeastern Ouachita Mountains. The more important localities are indicated in Figure 1 by the numbers 5 to 9. These rocks have been comprehensively studied by Williams.[1] In addition, Miser and Ross[2] have described peridotite dikes or sills

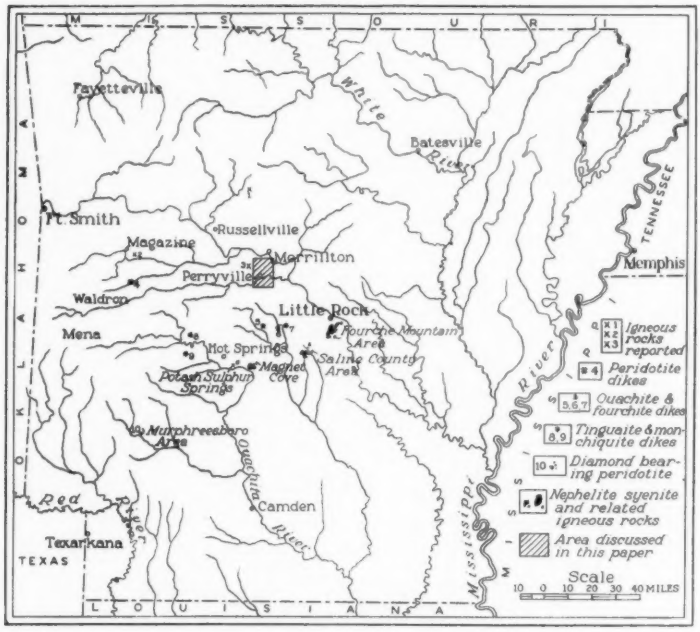

FIG. 1.—Map showing the previously known igneous rock areas of Arkansas, and the ones discussed in this paper.

in Scott County, at a considerable distance from the main intrusive area. The location of these sills is shown in Figure 1 by No. 4.

The principal intrusions described in this article occur almost in the geographic center of Arkansas, and lie within the lined rectangle shown in Figure 1. From Little Rock they may be reached by car along the roads which are shown by dashed lines in Figure 2. If the

[1] J. F. Williams, *op. cit.*

[2] H. D. Miser and C. S. Ross, "Peridotite Dikes in Scott County, Arkansas," *U.S. Geol. Survey Bull. 735–H* (1922), pp. 271–78.

range of hills between Perry and Perryville (see geologic section accompanying Fig. 2) is taken as the boundary between the Arkansas

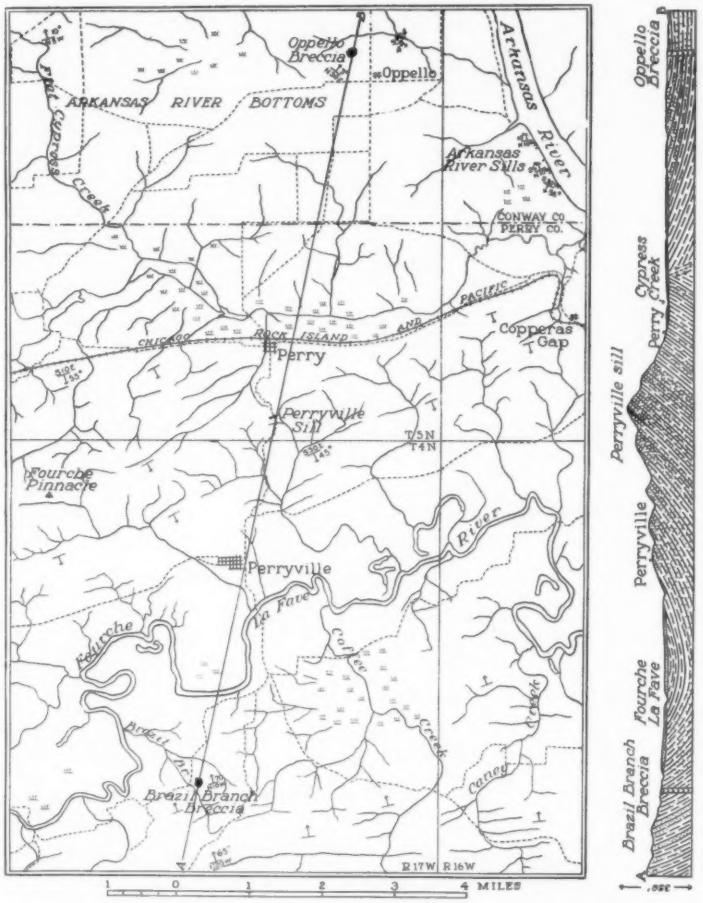

FIG. 2.—Map of the hachured area shown on Figure 1. The rocks shown in the structure section to the left all belong to the Aloka formation with the exception of the recent alluvium.

Valley physiographic province on the north and the Ouachita Mountain province on the south, the Brazil Branch breccia is in the latter

area, the Arkansas River sills and the Oppello breccia occur in the former, and the Perryville sill outcrops about on the very boundary.

The numbers 1, 2, and 3 in Figure 1 indicate other localities in Arkansas at which igneous rocks have reported. Locality No. 1, in the SW. 1/4 of the SW. 1/4 of Sec. 10, T. 10 N., R. 18 W., represents a possible outcrop of "blue granite" (syenite ?) which is so indicated on a field map prepared for the Arkansas Geological Survey in 1889 by H. E. Williams. The outcrop was at Thompson and Wiley's "gold mine," the openings of which were mostly in the bed of Hurricane Creek. At the time the locality was visited, the stream channel was so choked with débris that even the location of the old mine could not be ascertained definitely, and no igneous rocks were seen.

The mark ×2 in Figure 1 indicates the approximate location of a mass of peridotite, samples of which were sent to the Arkansas Survey for identification. This rock was encountered in digging a well somewhere in T. 5 N., R. 26 W., and probably in Section 4, but the man who sent in the sample was out of the state when the area was visited and the exact point of occurrence could not be determined in the limited time available.

Locality No. 3 is southeast of the village of Divide, and in either Sec. 18 or 19, T. 5 N., R. 18 W. According to Mr. Sadler the rock obtained here was darker than the breccia found at Oppello, but otherwise very similar. On account of its color it was mistaken for coal, and during the attempt to ignite it, the rock fused to a glass just as the Oppello breccia does. It seems likely, therefore, that there is in the area mentioned above another plug of the Oppello or Brazil Branch type. Lacking local guidance, however, it was impossible to find the outcrop, and samples of the rock were not seen.

Finally, the peridotite area in Scott County was visited, and owing to the great amount of erosion during the flood season of 1927, the sill was for the first time well exposed. The inclosing rock is black, clay shale of the Pennsylvanian Atoka formation. Both the country rock and the sill have an average dip of 74° N. 18° W. The peridotite was well weathered at the surface and down to a depth of between 20 and 30 inches, but there were also rounded masses of unweathered material found in the disintegrated zone.

The bed of Freedom Creek, in which the sill is best exposed, was also strewn with cobbles of the unweathered peridotite, which were standing up moderately well in the stream wash, but which showed a marked diminution in size downstream. The largest fragment seen measured $5 \times 13 \times 26$ inches. The contact of the igneous material with the shales is sharp, and even at the contact the country rock has not been appreciably altered. There is a 10-inch stratum of badly weathered material 32 inches above the main sill, which looks like an igneous breccia, and is somewhat similar to the material in the Perryville sill. No peridotite was found on the projected strike of the sill, but some of the material was found in a cotton patch in the SW. 1/4 of the SW. 1/2 of Sec. 35, T. 4 N., R. 26 W. This may possibly represent the position of another sill.

STRATIGRAPHY AND STRUCTURE

The surface rocks of the area shown in Figure 2 all belong to the Atoka formation, which is early Pennsylvanian in age. This formation comprises a monotonous succession of practically unfossiliferous sandstones and shales, in which a section aggregating 9,400 feet was measured, without either top or bottom being exposed. These strata are presumably underlain in this region by the same rather complete section of Paleozoic sedimentary rocks that appear beneath the Atoka to the south and southwest. If so, the thickness of the sedimentaries cut by the intrusion is, at the very least, 15,000 feet, and it may exceed 25,000 feet.

All of the formations in question have been involved in the severe crustal movements of the Ouachita Mountains, in which area the rocks are steeply folded and complexly faulted. The folds are much more open in the Arkansas Valley province to the north, and faulting is a less prominent feature. Even in the latter area, however, many of the beds are steeply inclined. With figure 2 there is given a structure section through the two volcanic necks along the line *AB*. All of the sediments shown belong to the Atoka formation with the exception of the recent alluvium, which is indicated as a veneer in the main stream bottoms. It is clear that the Oppello breccia has intruded essentially horizontal beds, whereas the Brazil Branch intrusion cuts steeply inclined strata. The nature of the

fault north of the Cypress Creek is effectively concealed by the alluvium, but the downthrow is apparently on the north.

SILLS

LOCATION AND FIELD RELATIONS

Arkansas River sills.—Four sills, hereafter described petrographically, outcrop on the southwest bank of the Arkansas River (which here flows in a southeasterly direction) about 5 miles south-southeast of Morrillton, in the NW. 1/4 of Sec. 17, and the SW. 1/4 of Sec. 8, T. 5 N., R. 16 W. (see Fig. 2). For convenience these structures are described in this article as the Arkansas River sills, and are designated in order 1 to 4, the southernmost sill being No. 1.

Arkansas River sill No. 1 outcrops as a row of deeply weathered boulders whose relationship to the inclosing shale has been somewhat obscured by river débris. The dip of the country rock at this point, however, is 26° N. 10° W., and from the distribution of the boulders there is every indication that the igneous material is interbedded rather than cross-cutting. The sill probably is not more than 11 inches thick, and, so far as can be ascertained, the adjacent shales have not been altered. Although the dip at the outcrop is north, this sill is very near the crest of the Redemption anticline,[1] for a very short distance to the south the dip is 56° S. 30° W.

Sill No. 2 outcrops in the bank of the river about 965 feet north of No. 1. Its total thickness varies from 3 to 5 feet, but it is possible that there may be two layers of igneous material with a thin shale stratum between. The dip at this point is essentially the same in amount and direction as that at the first sill, and the general relationships are similar. Approximately 230 feet north, sill No. 3 also outcrops in the river bank, but the dip at this point has diminished to 17° N. 10° W. Arkansas River sill No. 4 appears about 2,000 feet still farther north, where the dip is 10° N. 10° W. This layer is 24–30 inches thick, but since it weathers rapidly, and only appears at the water's edge, it is likely to be overlooked. A 16-inch stratum of granular black material, which is very micaceous, may represent a fifth sill, for it is macroscopically similar to sill No. 4, though it is so badly weathered that it has been impossible to

[1] One of a number of structures named and described by Mr. Croneis in a forthcoming report of the Arkansas Geological Survey.

make satisfactory sections of it. This stratum is stratigraphically 10 feet above sill No. 4, and it is directly overlain by a 15-inch coal bed, which is unaltered.

The Perryville sill (?).—The rock comprising this structure outcrops in a recent road cut on the new highway between Perry and Perryville, a little more than a mile north of the last-mentioned town. This material weathers with extreme rapidity, and the relationship of the structure to the inclosing strata is very much obscured, but it appears on both sides of the highway with the same strike as that of the sedimentaries. Ravines for several miles on either side of the road on the projected strike were carefully examined, but no similar beds were discovered. On account of the relatively poor outcrops, however, and the non-resistance of the rock itself, this does not necessarily prove their absence of these points. The main igneous mass has weathered to a compact, white clay in which are imbedded angular fragments of quartzite and arenaceous shale. This brecciated material apparently occurs in indefinite layers, several of which attain a thickness of at least 2 feet. Associated with the brecciated material is a dense, white, laminated, claylike rock which resembles bentonite. Bauxitic surface material, which appears down slope from the igneous outcrop, may have been derived from it.

The partially covered section in which the rocks occur has a calculated thickness of 27 feet. The igneous material is stratigraphically immediately above medium-bedded saccharoidal sandstones, and is subjacent to a thick section of poorly exposed, alternating sandstones and shales, all of the Atoka formation.

PETROGRAPHIC DESCRIPTIONS

Arkansas River sill No. 2 is composed of monchiquite. *Macroscopically* the rock is seen to be made up of a dense gray to black groundmass with phenocrysts of biotite, glassy black augite, a dull black amphibole, yellowish brown olivine, and white vitreous apatite. The phenocrysts average from a sixteenth to an eighth of an inch in maximum dimension. The biotite, which has a strong euhedral tendency, is the most abundant. Irregular grains of pyrite are also scattered through the rock.

Microscopically the phenocrysts of biotite, olivine, augite, apatite, and occasional amphibole are set in a groundmass of calcite. The olivine is found in unaltered euhedral to subhedral grains with parallel extinction, whereas apatite occurs either as euhedral crystals, the pyramidal terminations of which are more or less rounded, or as broken fragments. Pyrite is found in euhedral grains or in very irregular patches, and the biotite occurs either in euhedral or subhedral crystals. The pyroxene crystals are in most cases euhedral, but the amphibole is generally in irregular masses. The groundmass is composed of ragged, interlocking calcite crystals through which are distributed patches of pyrite, and microlites and stubs of unidentified minerals are also relatively numerous.

Arkansas River sills Nos. 1 and 3.—These sills are composed of ouachitite, which differs from the monchiquite mainly in its complete lack of olivine or its alteration products. In addition minor differences, probably of no great significance, such as the presence in ouachitite of magnetite rather than pyrite, also may be noted. The augite and biotite phenocrysts of sill 1 are surrounded by reaction rims of lucoxene. A red iron oxide is abundant in the groundmass of sill 3. Calcite veinlets cut the ouachitite, and in places the calcite is distinctly fibrous parallel to the vertical crystallographic axis.

Arkansas River sill No. 4 is so badly altered that we cannot determine the original rock with certainty. Macroscopically it is medium textured, in contrast to the typical fine-grained ouachitite, and grains of biotite and magnetite dot the specimen. Under the microscope apatite, magnetite, and biotite are seen set in a groundmass of calcite. The mineralogy suggests an altered ouachitite, but the texture implies a syenite.

Specimens from the *Perryville sill (?)* are so completely altered that only the apatite remains unchanged. In the hand specimen this rock is a white, compact clay in which are embedded white, euhedral crystals of apatite, together with small angular fragments of gray-black shale, and somewhat rounded pieces of dense, quartzitic sandstone, or more rarely of sandy shale. No igneous inclusions were found in the matrix in spite of a most diligent search throughout the entire outcrop.

The associated dense, white, laminated claylike substance, which has some of the features of a bentonite, may be simply a part of the badly weathered groundmass of the sill itself. On the other hand, there are the alternate possibilities that either the entire section represents a Pennsylvanian tuff, or that the rock is a part of another plug of the Oppello type. The final solution to the question requires better exposures and less completely weathered material for study.

The rock in question does not swell in water; but, according to Ross,[1] many bentonites do not so react. Under the microscope the rock consists of small flakes of a micaceous mineral whose approximate indices, determined by a comparison with Canada balsam, are $\alpha = 1.53$, $\gamma = 1.56$. These indices are too low for muscovite and suggest montmorillonite, a mineral characteristic of bentonite. The thin section, moreover, shows tension gaps similar to those in certain bentonites, but glass relict structure and volcanic minerals were not observed. We may finally note that this material does not resemble any of the sedimentary rocks of the region in which it occurs.

BRECCIAS: THE OPPELO BRECCIA

LOCATION AND FIELD RELATIONS

The rocks here described as the Oppello breccia outcrop about one mile west of Oppello, in the N. 1/2 of the SE. 1/4 of Sec. 2, T. 5 N., R. 17 W., on the W. J. Sadler farm. The country rock comprises typical sandy shales and shaly sandstones of the Atoka formation, which at this point are essentially flat lying. The land in the vicinity of the breccia is flat, rather poorly drained, and covered by a fairly thick soil-mantle. The natural outcrops, therefore, are few, and poorly exposed. It was possible, however, to take three dip readings, which are as follows: several hundred feet west of the exposure, 3° N. 30° E., and a similar distance both to the north and to the northeast, 4° S. 10° E. That these readings may be taken to suggest a regular dip of the country rock in toward the breccia is not clear, for the rocks on which they were measured are very irregularly bedded, so that the true attitude of the strata is determined with great difficulty, but certainly they indicate that the igneous mate-

[1] C. S. Ross, "Altered Paleozoic Volcanic Materials and Their Recognition," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. XII (1928), pp. 143–64.

rial has not domed the rocks in its vicinity. A fourth exposure of the country rock, which is not more than 50 feet east of the breccia, is covered with water in a small stream bed, and the dip cannot be determined. The rock at this point, however, shows no evidence of having been metamorphosed.

The matrix of the breccia is physically very strong, so that comparatively large charges of dynamite do not cause much shattering, but chemically the rock is non-resistant. The rock therefore does not outcrop naturally, and it is only from the distribution of the inclusions, which remain behind after the groundmass has completely weathered, that one may judge the size of the igneous mass. From the areal extent of this material, however, and from the distribution of the encircling sedimentary outcrops, it may be inferred that the igneous plug has a diameter of the order of magnitude of 300–500 feet.

The granite inclusions of the breccia represent the only certain surface occurrence of this rock in Arkansas.

PETROGRAPHIC DESCRIPTION

Macroscopically the Oppello breccia is composed of both angular and rounded fragments of shale, sandstone, and ouachitite, with lesser amounts of alkaline syenite and aegerite granite, which are set in a dense, gray groundmass containing conspicuous biotite crystals and, less commonly, black, glassy pyroxene grains. The shale fragments are very black, the sandstone is gray when fresh but reddish-brown when altered, and the ouachitite in most cases shows a reddish-brown peripheral ring about a tenth of an inch thick surrounding a gray core. The syenite and granite are medium-grained, semiporphyritic rocks composed of interlocking white and greenish-black grains. Some of the fragments are very angular; others, especially those of ouachitite, are strikingly spherical, a condition that apparently has resulted from the friction developed in the churning within the volcanic neck. The fragments vary in size from microscopic grains to pieces 4 inches in diameter.

The groundmass makes up about 25 per cent of the rock. It is composed of a very dense gray material in which are set euhedral crystals of biotite and less commonly of pyroxene. In altered speci-

mens the color of the groundmass is nearly white, and in some cases it has been stained yellow by limonite.

Microscopically the fragments may be classified as two general types: (1) fragments of adjacent country rock, and (2) fragments of igneous rocks associated with the vulcanism. The *fragments from the adjacent country rock* are shales and sandstones. The *shales* are very dense clastic rocks primarily composed of angular fragments of feldspar and quartz, but in many specimens accessory flakes of mica, which lie parallel to the bedding, are relatively abundant. Irregular patches of pyrite, limonite, leucoxene, and calcite also may be seen, but much of the shale is so dense that it cannot be resolved under the microscope. The *sandstones* are mineralogically very similar to the shales, and differ from them only in the size of the particles.

The *rock fragments of igneous origin* are mainly ouachitite, with lesser amounts of alkaline syenite and aegerite granite. The *ouachitite* is similar to the sill rocks already described, for it contains phenocrysts of biotite, augite, and apatite set in a groundmass of calcite. Irregular patches of pyrite appear, and analcite is present either as hexagonal grains or in vugs associated with calcite. Accessories include titanite, kaolin, and leucoxene. The *alkaline syenite* is composed of alkali feldspar with such accessories as aegerite, biotite, garnet (brown in thin section), pyrite, and analcite. In one type a great deal of calcite is present. The *aegerite granite* is made up of albite phenocrysts set in a groundmass of euhedral orthoclase (with a slight perthitic tendency), interstitial quartz, and aegerite. The aegerite occurs either as aggregates of many grains which extinguish individually, or as a group of isolated grains with simultaneous extinction. A very unusual amphibole with the following pleochrism has been noted: X = very light brown, Y = light purple with a brown tinge, and Z = light greenish-blue; $X < Y = Z$. It is probably a soda-iron amphibole.

Imbedded in the groundmass of the breccia are numerous crystals, particularly of biotite; less abundant are augite, apatite, and feldspar. In many cases these crystals have a strong euhedral tendency. The groundmass itself, which is partly altered to calcite and kaolin, is clouded and not generally resolvable under the microscope. A number of lines of evidence, however, indicate that the matrix is

pulverized rock: (1) wherever it is coarse enough to resolvable it is composed of angular, birefracting mineral fragments; (2) flow lines around the larger fragments, observed in many cases in flow breccias, are completely lacking; (3) the groundmass has not undergone the same alteration as the groundmass of the ouachitite sills (which is now calcite), a fact that implies a physical or chemical difference; (4) many of the rock fragments are distinctly rounded, as though by friction, and in no case do they show embayments such as result from magmatic corrosion. It is concluded, therefore, that the non-resolvable groundmass of the breccia is pulverized rock rather than devitrified glass which congealed *in situ*.

THE BRAZIL BRANCH BRECCIA

LOCATION AND FIELD RELATIONS

The rocks here described as the Brazil Branch breccia outcrop in the W. 1/2 of the SE. 1/4 of Sec. 29, T. 4 N., R. 17 W., about 3 miles south and a little west of Perryville. The country rock is dark, sandy shale or dense, black, slaty shale of the Atoka formation whose dip in this vicinity averages about 70° N. 10° W.; but 100 yards to the east of the exposure of the breccia the beds apparently are overturned, and the dip is 85° S. 10° E. The point of exposure (see Fig. 2) is a valley flat of Brazil Branch, a perennial tributary of Fourche la Fave River, which is somewhat covered by soil and old stream débris, but which apparently has not been inundated in recent years. The natural outcrop is a very poor one, but Mr. J. R. Myers, the owner, had at one time blasted a small opening in the rock, and exposed the material to the depth of several feet. This test pit was cleaned out and several others were dug; all encountered ouachitite and syenite fragments at very shallow depths. Several of the brecciated boulders blasted out of the hole are as much as 3 feet in their major dimension, and judging from the occurrence in the pit the rock is naturally very massive. In all cases where the rock has been exposed for some time the groundmass has weathered so rapidly that the inclusions now stand out in jagged relief on the surface.

The east-west dimension of the intrusion at the point of outcrop is small, for on both sides the sedimentaries are well bedded, un-

metamorphosed, and with normal dip within 250 feet of the test pit. Upstream, or southward, the sedimentary valley walls converge, so that the igneous material cannot extend far in that direction, but the actual southern limit cannot be ascertained on account of the stream wash. To the north the country is much flatter and the soil is thicker so that the rock may extend for some distance in that direction. A thorough examination failed to find any igneous surface material, however, and the rock may be regarded as having a limited areal extent. Another outcrop of the same material was reported as occurring upstream from the one described, but a most diligent search failed to reveal its presence.

PETROGRAPHIC DESCRIPTIONS

Macroscopically the Brazil Branch breccia is composed primarily of angular fragments of black shale set in a gray to black groundmass with biotite crystals. Less common fragments are ouachitite, nephelite-aegerite syenite, and shonkinite. The *nephelite-aegerite syenite* is a white rock speckled with black aegerite grains. When the rock is fresh, greasy nephelite grains are present, either as distinct hexagonal phenocrysts, not over 4 millimeters in diameter, or as irregular grains interstitial to the feldspars. One fragment of this rock measures nearly a foot in its maximum dimension, and judging from the freshness of one of its surfaces it is only a part of a still larger inclusion.

In the hand specimen this breccia differs from the Oppello breccia in two respects: (1) the fragments of the Brazil Branch breccia are mainly shale, whereas sandstone and ouachitite fragments are abundant in the Oppello breccia; (2) the fragments in the Oppello breccia are in many cases rounded, a condition that has not been observed in the material from the Brazil Branch locality.

Microscopically the fragments of the breccia may be studied in greater detail. The *black shale* is very difficult to resolve under the microscope, but minute flakes of mica, most of which are parallel to the bedding, are readily recognized, magnetite specks and dust are scattered over the slide, and much of the material may be chlorite.

The *nephelite-aegerite syenite* is composed primarily of alkali

feldspar and aegerite. Both orthoclase and albite are present. The former is the dominant feldspar and is greatly kaolinized. The albite is very fresh in appearance, lacks polysynthetic twinning, and is found either as perthitic streaks in the orthoclase or as independent grains. The aegerite commonly occurs as aggregates, and has the typical right-angle cleavage, yellowish-green pleochrism, and low extinction angle. Minor accessories are amphibole, titanite, analcite, nephelite, and apatite. The amphibole is of the same peculiar type as has been described as occurring in the aegerite granite found in the Oppello breccia. The analcite occurs in rounded or hexagonal grains of small size which are pink in transmitted light and isotropic under crossed nicols. A variety of the nepheliteaegerite syenite shows a distinctly banded structure. *A biotite shonkinite* inclusion is a fine-grained black rock which consists of dominant biotite with lesser amounts of pleochroic green amphibole and kaolinized orthoclase. The ferro-magnesian minerals are distinctly dominant, with apatite and magnetite as accessories. A fragment of *ouachitite* is composed of phenocrysts of pyroxene, biotite, apatite, and amphibole imbedded in a groundmass of calcite speckled with magnetite. Small blebs of garnet in some cases show a hexagonal outline. A unique feature of this ouachitite is the fact that the pyroxene commonly exhibits a core of aegerite-augite surrounded by a peripheral zone of augite; this is the reverse of the usual arrangement.

The *groundmass*, in the particular slides studies at least, differs considerably from that of the Oppello breccia. It is composed primarily of interlocking grains of calcite, but some chloritic material and many small garnets also are present. The garnets are isotropic, are ordinarily hexagonal in section, have an index greater than the ω index of calcite, and in many cases show a brown core. As far as we can ascertain the occurrence of garnets in ouachitite is unusual, but similar brown cores in microscopically colorless garnets have been described from the Arkansas alkaline syenites. In addition, there are scattered through the matrix subhedral crystals of brown hornblende, biotite, aegerite-augite, magnetite, and apatite. This assemblage strongly suggests that the matrix is an altered amphibole ouachitite. It will be recalled that the matrix of the Oppello breccia apparently is composed of pulverized rock.

THE AGE OF THE BRECCIAS AND SILLS

It is obvious that the breccias must be younger than the igneous rock fragments found in them, as well as more recent than the sedimentaries that they cut. The igneous fragments, it will be recalled, are ouachitite, nephelite syenite, aegerite granite, and biotite shonkinite. These fragments are exactly the same unusual rock types as those found in the Fourche Mountain, Saline County, Magnet Cove, and Potash Sulphur Springs Arkansan areas, and it seems reasonable to suppose that they originated at the same time. These peculiar alkaline rocks of the areas mentioned in the foregoing have been conclusively demonstrated by Miser[1] to be younger than early Cretaceous but older than late Cretaceous. It is apparent, therefore, that the breccias found near Oppello and at Brazil Branch most logically are to be correlated with the mid-Cretaceous Arkansan vulcanism. The sills, being of essentially the same type of rock, are also considered to have had their origin in the same period of vulcanism.

THE ORIGIN OF THE BRECCIAS

That the breccias are of igneous origin is clear. The angularity of the individual fragments, the large quantities of comagmatic igneous material, such as ouachitite, nephelite syenite, aegerite granite, biotite shonkinite, and the presence of such magmatic minerals as biotite, augite, and apatite amply demonstrate such an origin.[2] Unfortunately the precise structural relations of the breccias to the surrounding sediments are practically unknown from direct field observations. Consequently a number of working hypotheses for the origin of the breccia are analyzed below:

1. *The breccias were deposited contemporaneously with the Carboniferous rocks with which they are associated.*—Granting the Cretaceous age of the included igneous fragments, this is a sheer impossibility. In support of the Cretaceous age of the inclusions is the record of Cretaceous vulcanism yielding similar rare alkaline types less than 50 miles away, and the total lack of evidence for Pennsyl-

[1] H. D. Miser, "New Areas of Diamond Bearing Peridotite in Arkansas," *U.S. Geol. Survey Bull. 540* (1912), pp. 534–46.

[2] L. V. Pirsson, "The Microscopical Study of Volcanic Tuffs; a Study for Students," *Am. Jour. Sci.*, Vol. XL (1915), pp. 191–211.

vanian vulcanism in this general area. (The Hatton tuff lentil of the Stanley formation is Mississippian in age.)

2. *The breccias were deposited in Cretaceous time upon an old erosion surface.*—This hypothesis may be dismissed at once, since the Cretaceous erosion surface contemporaneous with the volcanic activity was at least 2,500 feet higher than the present position of the breccias, which is between 325 and 350 feet above sea-level. It is inconceivable that rock weathering as rapidly as the breccia does should survive from Cretaceous time to the present as an insoluble residual mantle.

3. *The breccia intrudes the sediments as sills.*—Part of the breccia is obviously of explosive origin. For the material to have been intruded as sills into sediments, which, in the case of the Oppello breccia at least, are essentially horizontal, involves insuperable mechanical difficulties.

4. *The breccias fill old volcanic necks which cut across the sediments.*—In favor of this hypothesis there are a number of facts: (*a*) Such a jumbled assemblage of rocks which are partly of igneous origin is typical in many volcanic necks as described by Geikie.[1] A high percentage of fragments of the country rock also has been noted by the same writer in a number of cases.[2] (*b*) In general appearance and lithology, the breccias are very similar to certain phases of the breccia found in the peridotite neck in Pike County, Arkansas.[3] (*c*) A very similar occurrence of breccia is found in association with the nephelite syenite sill at Beemerville, New Jersey, where small volcanic necks are filled with volcanic breccia very similar to those at Oppello and Brazil Branch.[4]

It may be recalled that an outcrop of sandstone found approximately 50 feet from the breccia at Oppello is practically flat-lying and unmetamorphosed. At first thought one might expect the sediments surrounding a volcanic neck to be altered and disturbed.

[1] Archibald Geikie, *The Ancient Volcanoes of Great Britain* (1897), Vols. I and II, pp. 76, 292, 293.

[2] *Ibid.*

[3] H. D. Miser and C. S. Ross, "Diamond Bearing Peridotite in Pike County, Arkansas," *Smithsonian Report* (1923), pp. 261–72.

[4] A. C. Spencer and others, *U.S. Geol. Survey Geol. Atlas*, Franklin Furnace Folio, No. 161 (1908).

Geikie, however, has cited many well-exposed volcanic plugs in which the wall rock is quite horizontal, and metamorphosed only for very short distances, such as from 10 to 30 feet.[1] The dimensions of the metamorphic aureole surrounding the Pike County peridotite neck are not given in the literature, but from the discussion of the country rock at that intrusion it may be inferred that they are small.

The size and shape of the necks at Oppello and Brazil Branch are unknown, due to the lack of sufficient outcrops, but it is believed that they are relatively small, perhaps not more than 500 feet in diameter. Such breccia-filled necks may be very small. The Pike County neck, including the associated peridotite, is 2,250 feet in its maximum dimension,[2] and several of the Beemerville intrusives are still smaller, one being not more than 400 feet in diameter. The peridotite and breccia-filled plugs of southern Ste. Genevieve County, Missouri, average about 300 feet in diameter,[3] and Geikie has recorded a neck whose largest dimension is only 60 feet.[4]

The ouachitite and monchiquite sills possibly are to be regarded as offshoots from the volcanic necks.

OTHER POSSIBLE MID-CRETACEOUS INTRUSIONS

The somewhat similar intrusions at Syracuse, Little Falls, and Ithaca, New York, at Masontown, Pennsylvania, Elliott County, Kentucky, and in southern Illinois, and western Kentucky are well known through a voluminous literature. This has been partially summarized by Jillson,[5] who believes that these intrusions, though certainly post-Carboniferous, are pre-Cretaceous, and thus of a different age from those (described by Williams) in Arkansas. It is true that in the Illinois-Kentucky fluorspar district the peridotite dikes in places are cut by faults, and that neither these faults nor the dikes have been seen to cut the Cretaceous sediments. The Cre-

[1] Archibald Geikie, *The Ancient Volcanoes of Great Britain* (1897), Vol. II, pp. 76, 279, 292, 295–96; Figs. 212 and 310.

[2] H. D. Miser, "New Areas of Diamond Bearing Peridotite in Arkansas," *U.S. Geol. Survey Bull 504* (1912).

[3] Marvin Weller, personal communication, December 1, 1928.

[4] Archibald Geikie, *op. cit.*

[5] W. R. Jillson, "Isothrustic Hypothesis," *Pan-Amer. Geol.*, Vol. XL (1923), pp. 251–58.

taceous in this area, however, is much younger than the Cretaceous beds of Arkansas which are cut by the intrusives, and the dikes in question show a marked diminution in number southward, none being known from the Cretaceous area itself. Hence the statement that neither the dikes nor the faults cut the Cretaceous beds of western Kentucky and Tennessee certainly cannot be taken as *positive* evidence that the intrusions are pre-Cretaceous in age.

Indeed, the writers wish to point out that most of these igneous structures, being composed of essentially the same material, being somewhat associated geographically, and having in many cases the same mode of intrusion, conceivably may be referable to the same period of vulcanism. In any case it follows that until further evidence accrues toward solving the age of the more northern intrusions, they may be assigned tentatively to the *dated* period of vulcanism which is responsible for the Arkansan igneous rocks. Furthermore, Marvin Weller[1] has recently discovered in southwestern Ste. Genevieve County, Missouri, about fifteen igneous plugs and dikes in which the rock is either a volcanic breccia or a peridotite similar to the igneous material found in the Arkansan intrusives. These structures cut only the earliest Paleozoic sediments, so that their exact age cannot be determined from field relations, but they logically may be taken as the connecting link between the Kentucky-Illinois intrusions on the east and the Arkansan igneous bodies to the south.

It is also interesting to note that the small igneous necks at Beemerville, New Jersey,[2] are composed of rocks strikingly similar to those found in the plugs that are described in this article. From field relationships the former structures can only be dated as post-Devonian, but structural similarities and the presence in both of similar rare alkaline rocks at least is somewhat suggestive of a contemporaneous origin. In addition, there is evidence of crustal movement during the later early Cretaceous along the Pacific Coast of the United States. Dikes and masses of serpentine and peridotite cut the Knoxville in this area, whereas the Upper Cretaceous (Chico)

[1] Marvin Weller, personal communication, December 1, 1928.

[2] A. C. Spencer and others, *U.S. Geol. Survey Geol. Atlas*, Franklin Furnace Folio, No. 161 (1908), pp. 12–13.

unconformably overlies the older formation, and has not been intruded.[1] This is a situation identical, so far as magma, time, and structural relations are concerned, with that in the Arkansan intrusions. Most of the various lines of evidence, therefore, lend some weight to the suggestion that all of the intrusions previously mentioned were formed at approximately the same time, which was probably late-early or mid-Cretaceous, but the writers are aware that the similarities pointed out in the foregoing may be either coincidental or simply the result of similar methods of intrusion and similar magmas.

POSSIBILITY OF DIAMONDS

The only previously described volcanic neck in Arkansas is that in Pike County, in which tuff, breccia, and peridotite are found. The diamonds occur mainly in the peridotite breccia, and only very sparingly in the intrusive peridotite. Apparently, however, diamonds, where found in place, are always genetically associated with the latter rock. Inasmuch as no peridotite has been found in the Oppello or Brazil Branch breccias, there is no reason to suspect the presence of diamonds in either. It may be advisable, however, to study the areas more carefully to determine positively whether or not peridotite is associated with the breccias. The preliminary studies seem to indicate that, if present, peridotite must occur in very minor amounts.

GAS POSSIBILITIES

On account of the small size of the intrusions and the fact that the country rock is neither appreciably altered nor structurally disturbed, it is thought that these igneous bodies probably affect the possibilities for gas only very slightly. It happens also that the intrusions described in this article are so located that they are in areas structurally unfavorable for gas, so that the ones here considered at least have very little bearing on the possible productivity of the Arkansas Valley province as a district.

[1] F. M. Anderson, "Cretaceous Deposits of the Pacific Coast," *Proc. California Acad. Sci.*, Vol. II (1902), pp. 53–55.

THE SAGANAGA GRANITE OF MINNESOTA-ONTARIO[1]

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ABSTRACT

The oldest batholith along the Minnesota-Ontario boundary is that at Saganaga Lake. It is the only one older than the Ogishke sediments and is therefore assigned to the Laurentian. Since a still older granite gneiss has been found farther east, the Saganaga granite arose late in Laurentian time. It is a roughly oval mass about 15×25 miles across and has nearly vertical walls. The main rock, 85–90 per cent of the mass, has long been known and is very uniform sodic hornblende granite. The local phases, described in some detail, include syenite, shonkinite, and hornblendite. For such an old formation the rocks are very little altered.

Measurements and chemical analyses give data for tables and diagrams of the differentiated series. The ratio of potash to soda increases with increasing silica toward the central part of the mass. This series resembles that in the Giants Range which is of Algomian age; also some others of later eras.

INTRODUCTION AND ACKNOWLEDGMENTS

Of the several batholiths in northern Minnesota that have been supposed to be of Archean Laurentian age, it now seems that the Saganaga granite is the only one that is demonstrably older than the Ogishke-Knife Lake sediments.[2] As the sole representative of this Laurentian batholithic activity in the region it seemed worthy of a restudy, including a reconnaissance into the Canadian extension of the mass, and a much closer study of the petrographic variations it exhibits.

Since 1881, when N. H. Winchell visited Saganaga Lake, the general geology of the district has been discussed in some ten or more published papers.[3] Careful field and laboratory work has been need-

[1] Published by permission of the Director of the Minnesota Geological Survey.

[2] Following the usage of the U.S. Geological Survey we consider these sediments Lower-Middle Huronian. The later age of the Vermilion and other granites is shown in *Jour. Geol.*, Vol. XXXIII (1925), p. 470.

[3] N. H. Winchell, *Minn. Geol. and Nat. Hist. Survey Tenth Ann. Rept.* (1882), p. 93; A. Winchell, "Minn. Geol. and Nat. Hist. Survey," part of *Sixteenth Ann. Rept.* (1888), pp. 211–33 and 330–34; "Conglomerates Enclosed in Gneissic Terranes," *Amer. Geol.*, Vol. III (1889), p. 153; W. H. C. Smith, "The Geology of Hunters Island," *Ann. Rept. Can. Geol. Survey*, Vol. V, Part I-G (1890–91), pp. 19 and 75–76; A. C. Lawson, "Lake Superior Stratigraphy," *Amer. Geol.*, Vol. VII (1891), p. 324; H. V. Winchell, "Geologic Age of the Saganaga Granite," *Amer. Jour. Sci.*, Vol. XLI (1891), pp. 386–90; U. S. Grant, "Stratigraphic Position of the Ogishke," *Amer. Geol.*, Vol. X (1892), p. 7; "Field

ed to bring the several workers into general agreement as to the relations of the mass to its surroundings. The petrographic peculiarities have been noted briefly in connection with the general studies, but no published description is more detailed than the page and a half given by A. Winchell in 1887, and there has been but one brief and unsatisfactory analysis.[1] All petrographic notes have referred to the Minnesota portion of the mass almost exclusively.

I am indebted to the Director of the Minnesota Geological Survey for permission to make the study, and to the University of Minnesota for an allotment from the University Research Funds for some chemical analyses. Thanks are also due the field assistants, Mr. Sam A. Grantham and Dr. N. W. Taylor. Some details of petrography were worked out by A. J. Bauernschmidt.

GENERAL GEOLOGY

The Saganaga granite lies about 30–40 miles north of Lake Superior, and occupies a roughly oval area, about 100 square miles in Minnesota and nearly as much in Ontario (see Fig. 1).

Although Saganaga Lake and some other lakes occupy a high percentage of the area of the batholith, exposures are numerous and the glaciated wave-washed shores show the fresh rock very clearly. Traverses over the usually smooth, rounded hills show little but what can be seen as well along the canoe routes.

The mapping of the boundary of the batholith on the north, south, and west is to be credited largely to Dr. Grant,[2] who about 1893 cleared up the confusion that early developed in distinguishing a granite from a "recomposed" granite derived from arkose. Some small satellitic stocks occur between Gunflint Lake and the main granite, most of them too small to show accurately on the map. Others may occur farther east.

Observations on Certain Granite Areas," *Minn. Geol. and Nat. Hist. Survey Twentieth Ann. Rept.* (1893), pp. 83–95; *Minn. Geol. and Nat. Hist. Survey Final Rept.*, Vol. IV (1899): "Geology of Cook County," pp. 321–23, and "Geology of the Akeley Lake Plate," p. 467; J. M. Clements, "The Vermilion Iron-bearing District of Minnesota," *U.S. Geol. Survey Mono. 45* (1903).

[1] Given in the *Minn. Geol. and Nat. Hist. Survey Ann. Repts. 21 and 23;* and repeated three times in the *Final Report,* Vol. V.

[2] *Twenticth Ann. Rept.* (1893).

The relations of the granite to the Keewatin greenstone, though long discussed, are rather well determined.[1] The granite intrudes the greenstone and by contact metamorphism turns it into a hornblende schist for some distance.

The relations of the granite to the Ogishke conglomerate have been more discussed but the detailed work by Grant,[2] showing that

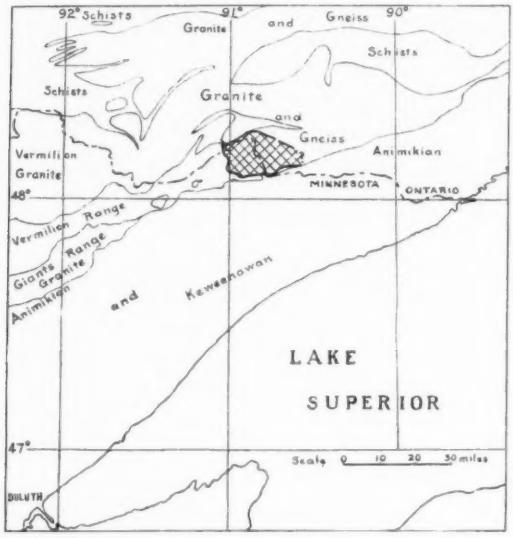

FIG. 1.—Sketch map showing (cross-hatched area) the location of the Saganaga granite and other formations north of Lake Superior.

the Ogishke and Knife Lake sediments unconformably overlie the granite, has been confirmed by later studies.

These two are the only pre-Cambrian formations in contact with the granite along the west and south except the Animikie iron formation which unconformably overlaps the granite and greenstone near Gunflint Lake and farther east.

Another contact formation has been discovered, however, in

[1] Clements, *op. cit.* H. V. Winchell alone maintained that the granite was derived from greenstone (*Amer. Jour. Sci.*, Vol. XLI [1891], pp. 389).

[2] *Op. cit.*, Vol. IV, p. 322.

Ontario to the northeast of the granite batholith. This is an older gneiss not distinguished on earlier maps of the Lake Superior region.[1] The granite was supposed to extend some 60 miles N. 60° E.[2] After visiting a large number of outcrops on Saganaga Lake the writer spent a few days on Northern Light Lake and in traverses between

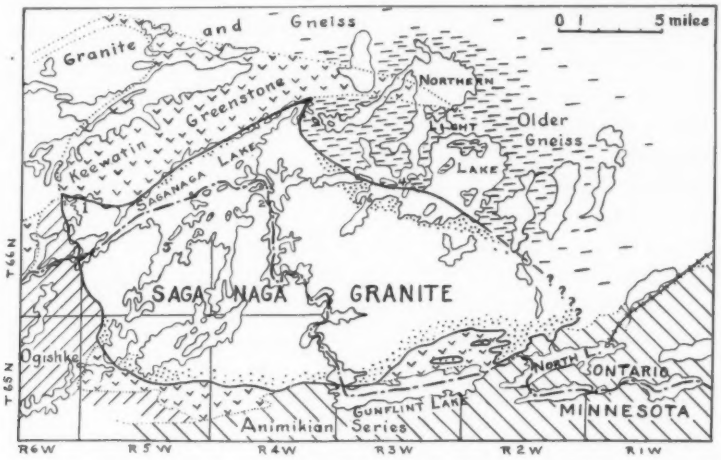

FIG. 2.—Map of the Saganaga batholith, showing its contact formations and special phases. Stippled areas are the border phases. 1, Cache Bay of Saganaga Lake, where the border phase is missing and granite porphyry intrudes the greenstone. 2, Saganaga Falls, north of which is the shonkinite and hornblendite. 3, Wonder Island, showing inclusions of hornblendite in granite. 4, In Northern Light Lake an island shows granite dikes intruding older gneiss. 5, Typical granite, for analysis. 6, Well-exposed gradation from typical granite to border phase.

that lake and the international boundary south of it. Most of this area exhibits only a much older-looking granite gneiss. This differs so greatly in color and texture, and in its abundance of inclusions, that it seemed hardly possible to consider it simply a different phase of the same batholith. A small amount of exploration served to outline the area of the characteristic Saganaga granite as distinct from the older gneiss. This new boundary is shown in Figure 2. No at-

[1] Plate I of *U.S. Geol. Survey Mono. 45;* data probably from maps of the Canadian Geological Survey.

[2] *Can. Geol. Survey Ann. Rept.*, Vol. V (1890–91), p. 19G.

tempt has been made to explore the gneiss farther than to know that it extends several miles in its monotonous heterogeneity, whereas the Saganaga granite with its almost unique petrographic features is equally monotonously uniform for 10–20 miles in the other direction. It is a problem outside the present study to determine whether or not other batholiths or outliers of the batholith occur in the gneiss farther east in Canada, and whether any of them show transitions into the gneiss. In the area here studied, the two seem distinctly of different ages. At a few places near the granite, the gneiss is cut by small dikes of hornblende granite which seem to be apophyses from the main mass (see location 4, Figs. 2, 3, and 5).

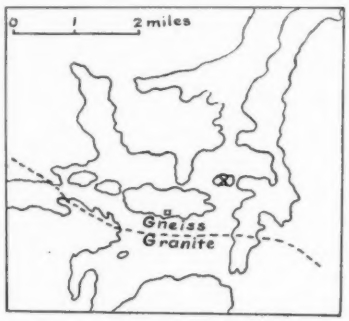

FIG. 3.—The location of good exposures of dikes of hornblende granite in the older gneiss, on Northern Light Lake. Detailed sketch of the country around the point marked "4" in Figure 2. Northeast of a large island is the smaller island indicated by a cross, where exposures are best.

The differences in chemical and mineral compositions of the granite and the main body of gneiss are also against any assumption that the gneiss is an early phase of the same batholith (see Fig. 16). The gneiss is lighter in color, and is characterized by about 5 per cent green biotite, while the granite is hornblendic and probably never reached a stage of evolution that made biotite the stable product of crystallization; the few biotitic phases that do occur in the granite near the border have a red-brown biotite. An analysis of the gneiss is No. 6 of Table I. A second sample contained 4.20 per cent soda and 1.10 per cent potash.

The probability of granites of two distinct periods was noted also by Gill in some mapping north of the international boundary.[1] East of Shekaka Lake, near North Lake, he finds inclusions of gneiss in coarse fresh granite. It is uncertain whether Gill was referring to the gneiss here described. Several outcrops of metamorphic gneisses north of North Lake show that the granitoid original rock has been

[1] J. E. Gill, *Can. Geol. Survey Summary Rept. for 1924*, Part C (1926), p. 36.

crushed almost into a schist and the schistosity later has been crumpled by pressure in another direction. Detailed work in Canada would be needed to determine whether the rock was older gneiss or a gneissic border phase of the granite of the Saganaga batholith.

The contact of granite and greenstone wherever seen is nearly vertical, but is confused by dikes in the greenstone, and the relief of the district is so low that contacts show vertical sections of relatively few feet. The contacts of granite and later sediments show an unconformity, but there is a further complication that seems to be due to later folding.[1]

The vertical contacts suggest that the batholith has been deeply eroded. This is confirmed by a notable scarcity of pegmatites and inclusions of the adjacent formation such as might characterize an upper portion of a batholith. Possibly the outcrops represent a moderately deep zone in a batholith where magma rose by crowding aside its walls rather than by stoping. This, however, is admittedly a suggestion based on slender evidence, for the older granite gneiss which now adjoins the granite on the northeast is full of inclusions of hornblende schist, injected *lit-par-lit* most intricately (Fig. 4).

AGE

The relations just described show that the Saganaga granite is later than Keewatin greenstone, and earlier than Knife Lake slate and Ogishke conglomerate. Any granite developed between these is Laurentian and a representative of the oldest period of batholithic intrusion. The more widely distributed Algomian granites in the region intrude the Ogishke conglomerate. The Saganaga granite therefore is Laurentian in the sense that it formed in the older of two pre-Animikian batholithic periods.

More specifically, since there seem to be at least two batholithic invasions in this interval, the Saganaga granite seems to be a late development in the time of Laurentian batholithic activity.

NAME

The granite was called by a formation name, "Saganaga granite," in a report by N. H. Winchell on field work done in 1881.[2] Several reports of the Survey, and papers by the Survey geologists, used

[1] Clements, *op. cit.*, pp. 272–73. [2] *Op. cit.*

the name during the following twenty years. The name is particularly appropriate, for Saganaga Lake is the largest lake in the granite area, and the intricate shore line estimated at 100 miles in length shows granite along a high per cent of that length; the islands add about as much more.

FIG. 4.—Gneiss typical of Northern Light Lake, resulting from injection of greenstone *lit-par-lit*, and metamorphism.

DESCRIPTIONS

GENERAL STATEMENT

The Saganaga batholith is largely dominated by a single type of granite—a somewhat sodic hornblende granite with conspicuous "phenocrysts" of quartz (Fig. 6). Most of the area shows only monotonously uniform granite of this type, with scarcely an inclusion, a pegmatite, or an aplite. A few small outcrops show inclusions and dikes, and some local variations occur in the midst of the granite area; but the most important areas that differ petrographically from the main granite constitute a border, or zone, roughly a mile in width, along the south, east, and northeast sides of the batholith. No doubt the west side had originally a similar border, but the present western boundary resulted from erosion which cut away the border rock along most of the granite before the sediments of the Ogishke-Knife Lake series were deposited.

It is estimated that in the area examined the main phase constitutes 85–90 per cent of the mass; a border type of granite is estimated at 6 per cent and border syenite at 3 per cent of the mass; shonkinite may form 1 per cent, and hornblendite is probably much

FIG. 5.—Dike in gneiss; apparently an apophysis from the Saganaga granite

less than 1 per cent of the mass. The inclusions indicate that hornblendite was earlier to solidify than shonkinite, and both are earlier than syenite and granite.

PETROGRAPHY OF THE MAIN MASS

The dominant rock of the Saganaga batholith is pink to white in outcrop and so massive as to form smoothly rounded *roches moutonnées*. Joints are widely spaced and irregular in direction. Locally there is a slight tendency to platy jointing dipping at low angles north or south.

The texture is medium granitoid with remarkable large quartz aggregates, many of which seem to be hexagonal phenocrysts $\frac{1}{8}$–$\frac{1}{2}$ inch across (see Fig. 6). These are not so perfect as to prove that they grew early in the magma, but they at least strongly suggest that quartz crystals were large before they were interfered with by adjacent crystals. One of the porphyry dikes near the granite (Fig. 13) also indicates that quartz grew large before final crystallization.[1]

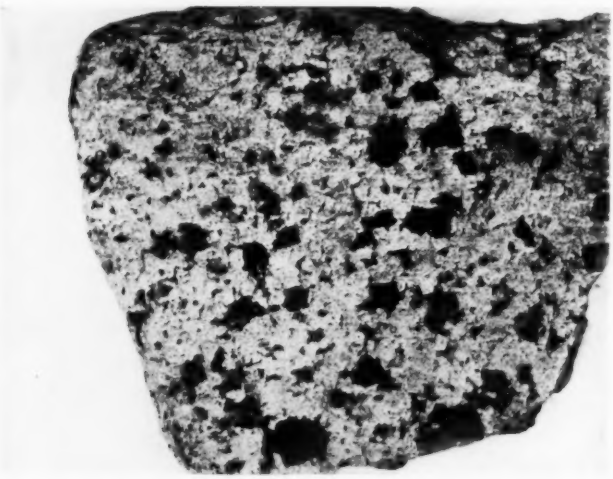

FIG. 6.—Weathered specimen of Saganaga granite. The darker spots are smoky quartz.

In a few cases a poikilitic texture is revealed by a reflection from a cleavage face of orthoclase up to an inch or more in diameter, this crystal being so filled with grains of plagioclase, quartz, and hornblende about an eighth of an inch in diameter that the whole mass seems evenly granitoid except when the cleavage of the feldspar is noted.

Nearly all the fresh rock shows two feldspars in hand specimens; the plagioclase yellowish white and weathering white, and the ortho-

[1] Some of the apparently single phenocrysts of the porphyry prove to be composite when studied under the microscope, but they seem to be glomero-phenocrysts rather than broken grains.

clase pink to red, but also in some places weathering white. The quartz varies from milky to smoky, but in most cases is so different in color from the feldspar that the "phenocrysts" are conspicuous. They resist weathering considerably better than feldspar, and stand out in relief on many outcrops.

Several specimens were collected to determine the cause of the variation from red to white in outcrops close together and otherwise alike. The red weathering has been said to be especially strong where the granite is most altered.[1] It was found, however, that the greenish-white rock showed more sericite as well as less hematite than the red one, and partial analyses (Table I) show that the green rock is more hydrous. Probably the hot waters that formed sericite of feldspar formed pyrite of the iron minerals, destroying the red color that is normal in most of the orthoclase of the mass. Weathering might again oxidize the iron to hematite, but the rearrangement would be likely to leave it in bunches, not widely disseminated as a stain.

Under the microscope the texture is commonly hypautomorphic granitoid, but with certain peculiar features. The plagioclase and hornblende show many subhedral or corroded grains.

The quartz which is so striking a feature in the field shows structures not easily interpreted. There is much less indication of crystal form than was supposed from field study, and the large areas in thin section are in most cases aggregates of grains in various optical positions (see Fig. 8), quite aside from the strain shadows that give a single grain near extinction the appearance of an aggregate.[2] In the quartz areas are oligoclase grains that seem to be remnants of good crystals, now much corroded (see Fig. 9); and along the outside of many plagioclase grains there is myrmekite testifying to a certain amount of attack on early minerals by the late quartzose magma. The quartz aggregates are therefore attributed to late growth and magmatic replacement rather than to early phenocrysts and later breaking-up. Some field relations also seem to favor such an interpretation. A few rods north of Saganaga Falls in the midst of the area

[1] Clements, *op. cit.*, p. 266.

[2] N. H. Winchell (*op. cit.*, Vol. V, p. 314) speaks of the quartz grains as in "many parts, the result of a crushing to which they have been subjected." There is little to indicate dynamic action.

of typical granite there are some islands on which the rock has only a few quartz "phenocrysts," and these are in ill-defined bands or

TABLE I

ANALYSES OF TYPICAL SAGANAGA GRANITE AND OLDER GNEISS

	Type Locality			Red	Green	Older Gneiss
	Recent, M1915	Old Survey, G686				
	1	2	3	4	5	6
SiO_2	68.81	69.34	.....	.....	.....	73.01
Al_2O_3	16.30	17.25	.....	.....	.....	15.05
Fe_2O_3	1.95	2.46	.....	.89	.24	Trace
FeO	.75	.....	.....	1.62	2.50	.99
MgO	.91	1.18	.....	.....	.....	1.62
CaO	2.19	3.43	.....	.....	.....	3.44
Na_2O	4.97	4.33	4.78	3.42	2.56	4.20
K_2O	2.29	.71	3.06	2.84	2.45	.88
H_2O+	1.38	1.17	.....	1.26	2.04	.64
H_2O-	.12	.....	.....	.....	.....	.12
CO_2	.30	.....	.....	.....	.....	.06
TiO_2	.22	.....	.....	.....	.....	.....
ZrO_2	.02	.....	.....	.....	.....	.....
P_2O_5	.07	.....	.....	.....	.....	.....
S	.03	.....	.....	.....	.....	.....
Cr_2O_3	.02	.....	.....	.....	.....	.....
MnO	.02	.....	.....	.....	.....	.....
BaO	.10	.....	.....	.....	.....	.....
Total	100.45	99.87	.....	.....	.....	100.01
Specific gravity	2.657	.....	.....	.....	.....	2.657

1. Saganaga granite (Lassenose), a sodic granite from island in Sec. 22, T. 65 N., R. 5 W (analysts, F. F. Grout and A. J. Bauernschmidt). Mode: 20 per cent quartz, 25 per cent orthoclase, 48 per cent oligoclase, 7 per cent hornblende and its alteration products; measured by F. F. Grout on two thin sections. It should be noted that neither section included a quartz "phenocryst." Thin sections of average size are not fair samples of such coarse rocks.
2. The same as the foregoing (analyst, A. D. Meeds, *Minn. Geol. and Nat. Hist. Survey Final Rept.*, Vol. V, p. 902).
3. Alkali determination by Bauernschmidt on specimen in the old Survey collection, supposed to be the one tested by Meeds.
4. Red weathering. } 1,900 paces N., 600 paces E. of Sec. 9, T. 65 N., R. 5 W
5. Greenish-white weathering. } (analysts, F. F. Grout and George Ward).
6. Older gneiss (Amadorose) Northern Light Lake (analysts, F. F. Grout and George Ward).

schlieren, as if developed along zones or planes by some movement of the late magma. The absence of such "phenocrysts" in much of

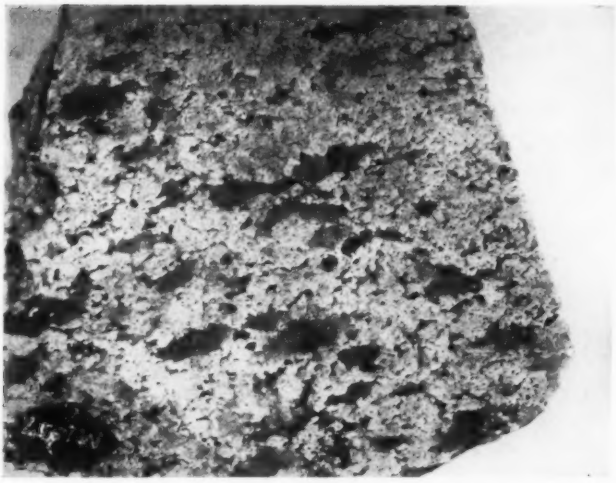

FIG. 7.—Trachitoid Saganaga granite. The structure seems to be primary

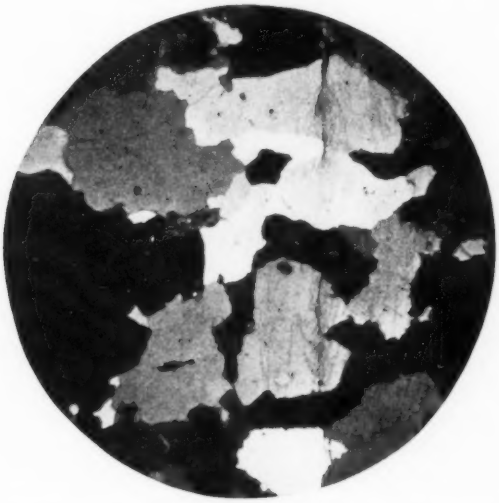

FIG. 8.—Showing the complex aggregate nature of some of the apparent phenocrysts of quartz in the granite. Crossed nicols, ×20.

the border zone and in certain belts in the main mass might also be explained as a result of completion of solidification before the residual mass had evolved so far as to attack the early feldspars. Finally, some dark patches[1] a few feet across which suggest inclusions in the granite have quartz "phenocrysts" as if the residual magma had partly replaced them, along with the replacement of early crystals of the granite itself. The occurrence of fluorine in the rock may also indicate deuteric action.[2]

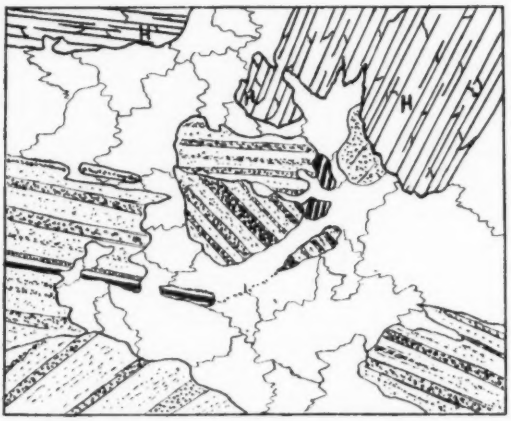

FIG. 9.—Saganaga granite showing: white, aggregate of quartz with sutured contacts; stippled and banded, plagioclase, evidently corroded by the quartz; *H*, hornblende, may also be corroded. ×30.

Orthoclase in the rock seems to have formed before the quartz, or perhaps at the same time with it. It is clearly later than the hornblende and plagioclase, which are inclosed in it poikilitically and in many cases corroded. Perthitic intergrowths are seen in but few places.

The average of the modes of all thin sections available indicates that the granite contains about 28 per cent quartz, 25 per cent orthoclase, 35 per cent acid plagioclase, and 8 per cent hornblende and its alteration products. Quartz, orthoclase, and plagioclase vary

[1] E.g., on the east side of a point in the SE. ¼ of Sec. 22, T. 66 N., R. 5 W.

[2] P. Eskola, "Petrology of the Orijärvi Region," *Bull. Com. Geol. de Finlande* (1914), pp. 29–30.

in their proportions somewhat, and the more quartzose or more potassic varieties do not seem to be related to the position in the

TABLE II

ANALYSES AND MODES OF SPECIAL PHASES OF THE SAGANAGA BATHOLITH

	7	8	9	10	11	12	13
SiO_2	49.81	50.41	58.27	63.47	65.91	.....	.....
Al_2O_3	11.43	15.93	15.31	17.11	19.11	.....	.....
Fe_2O_3	2.77	6.13	1.51	.78	Trace	.....	.....
FeO	7.22	5.36	3.82	2.36	1.47	.....	.....
MgO	12.18	5.32	6.77	2.72	1.12	.....	.....
CaO	13.14	10.55	8.36	6.56	4.86	.....	.....
Na_2O	1.10	2.80	3.26	3.78	4.78	5.44	4.49
K_2O	.91	1.25	1.61	2.39	1.72	3.59	.94
H_2O+	1.58	1.38	.72	.66	1.24	.....	.....
H_2O-	.14	.12	.20	.18	.16	.....	.....
CO_2	.....	.10	.....	.....	.....	.....	.....
TiO_2	.35	.40	.62	.30	.09	.....	.....
ZrO_2	.....	.02	.....	.....	.....	.....	.....
Cr_2O_3	.....	.12	.....	.....	.....	.....	.....
MnO	.....	.24	.....	.....	.....	.....	.....
BaO	.....	.02	.....	.....	.....	.....	.....
Total	100.63	100.15	100.45	100.31	100.46	.....	.....
Specific gravity	2.967	2.967	2.794	2.707	2.676	2.582	.....

7. Hornblendite (Auvergnose), SE. ¼ of Sec. 33, T. 66 N., R. 4 W., north of Saganaga Falls (analyst, George Ward). Mode: 5 per cent orthoclase, 2 per cent plagioclase, 93 per cent hornblende.
8. Shonkinite (Basswood type) (Auvergnose), north of Saganaga Falls (analysts, F. F. Grout and A. J. Bauernschmidt). Mode: 3 per cent quarts, 10 per cent orthoclase, 20 per cent oligoclase, 65 per cent hornblende, 2 per cent accessories.
9. Porphyritic shonkinite (Andose), island in northeast bay of Saganaga Lake, Sec. 14, T. 67 N., R. 4 W., as of United States (analyst, G. Ward). Mode: 5 per cent quartz, 15 per cent orthoclase, 25 per cent oligoclase, 55 per cent hornblende.
10. Gray granite (Tonalose), northernmost United States island on Saganaga Lake, Sec. 31, T. 66 N., R. 4 W. (analyst, G. Ward). Mode: 12 per cent quartz, 20 per cent orthoclase, 55 per cent oligoclase, 13 per cent hornblende.
11. Gray-granite border phase (Yellowstonose), Canadian shore Saganaga Lake, SE. ¼ of Sec. 20, T. 66 N., R. 4 W., as of United States (analysts, F. F. Grout and G. Ward). Mode: 21 per cent quartz, 22 per cent microcline, 50 per cent oligoclase, 5 per cent hornblende, and considerable secondary minerals.
12. Red granite, bearing purple fluorite, in midst of Saganaga batholith, Sec. 14, T. 66 N., R. 5 W. (analyst, F. F. Grout).
13. Granite porphyry dike, apparently related to Saganaga batholith, north of Cache Bay (analyst, G. Ward).

batholith (see Table II). The measured modes suggest more variation than the field observations, and it is probable that they are more

variable than the rock itself, because a small thin section does not fairly represent such a coarse-grained rock. The plagioclase has about 10 per cent of the anorthite molecule, some of the specimens to be classed as albite, others as oligoclase. There is probably some soda also in the orthoclase. Microcline occurs in a few small areas in place of orthoclase. Accessories are commonly apatite, zircon, magnetite, and titanite. Very locally there are fluorite and pyrite, but they seem to be introduced, probably as emanations from a pegmatite near by, but possibly as deuteric or late magmatic minerals. Distinctly later introductions include calcite, hematite, quartz, and epidote in veinlets.

The alteration of the minerals is not extreme, but seems to have occurred at more than one stage. The texture suggests that the early essential minerals were medium to acid plagioclase and hornblende or some other mafic mineral. The magma residue from which orthoclase and quartz grew later attacked the plagioclase, developing myrmekite and perthite and leaving the plagioclase forms notably corroded or even separated, as seen in thin section, into several parts. The myrmekite and outer zones of the plagioclase are less attacked by sericitization than the main grains. The same late magma no doubt attacked the mafic mineral. As noted below in the description of a border rock, the original mafic mineral in some parts of the batholith may have been a pyrozene, but if so it is nearly all recrystallized to hornblende. Most of the hornblende looks primary. Finally, there seems to have been a very widespread change in the hornblende to an aggregate of uralite, biotite, chlorite, and epidote in variable proportions. This last group of minerals may possibly have formed before the rock cooled, but since the whole region has suffered later deep-seated deformation, the alteration to chlorite and epidote is probably metamorphic. Accompanying that change there was much alteration of the rest of the rock to sericite, calcite, and leucoxene, more rarely muscovite, prehnite, magnetite, and secondary quartz. Weathering has formed some kaolinite and limonite. Much shattering appears in a few of the specimens, and the network of veinlets is filled with sericite, chlorite, calcite, and other secondary minerals; as a whole, however, the rock is much less altered than would be expected from the known deformation of the region since Laurentian time.

The following analyses of typical Saganaga granite are available. That by Meeds is not very satisfactory as to completeness, and, as was noted in the early Survey reports does not agree at all well with the microscopic measurement of the minerals in the rock.[1] Since the recent analysis showed much more potash in a sample from the same island, a new determination of alkalies was made on the specimen in the old collection of the Survey. It seems quite certain from the results in column 3 that the rock has three or four times as much potash as the older analysis indicated. An analysis of the older gneiss adjoining the granite is added for comparison.

It is evident that some of the feldspar that seems to be orthoclase has a great deal of soda, and the rock is a sodic granite. It is granodiorite (227,′ very near 227″) in Johannsen's table, and in most respects it approaches granodiorite and quartz monzonite; but it is low in lime so that the plagioclase is more acid than in the original granodiorites and monzonites.

GNEISSIC PHASES

The term "gneiss" covers a number of distinguishable structures. There is very little injection *lit-par-lit* by the granite into older greenstone; and in this respect, as stated above, it contrasts markedly with the older gneiss on Northern Light Lake. There is also very little rock in the area here outlined which has been sheared or mashed as much as the older gneiss, forming smeared streaks from the original well-defined crystals. Relatively few specimens show even a mortar structure or any microscopic faults, though a few can be found. This kind of metamorphic gneiss is almost wholly limited to the outer or border zone of the area.

There remain two other features described as gneissic, both of which are primary rather than metamorphic—a flow structure and a tendency to slabby parting.

The flow structure or trachitoid texture appears in the main type of granite chiefly as a parallelism of elongated quartz "phenocrysts" resembling the augen of a truly metamorphic rock (see Fig. 7). Microscopic examination shows no more evidence of deformation in these quartz lenses than in the equidimensional "phenocrysts," and

[1] U. S. Grant, *Minn. Geol. and Nat. Hist. Survey Final Rept.*, Vol. V (1900), p. 315. Grant says there is so little potash feldspar indicated by the analysis that the rock may be properly a diorite.

a close inspection shows unbroken hornblende needles pointing in the same direction as the lenses. It is therefore believed that the structure is primary. Relatively little of the mass shows this feature, but it can be well seen near the first fall in the boundary river north of Gunflint Lake, and in places from there north almost to the northeast bay of Saganaga Lake. The strike is in general a little north of east.

Trachitoid textures are perhaps more common in the equigranular border-zone rocks described below.

The slabby parting in typical Saganaga granite is well seen at Saganaga Falls, but most of that structure occurs in those phases of granite without the quartz "phenocrysts." A very striking example outcrops on an island in Sec. 31, T. 67 N., R. 4 W. (see Fig. 10). The structure seems to be a result of some slight parallelism of grain, and thus related to the trachitoid texture already mentioned. It is not a metamorphic feature that will distinguish the Laurentian in any way from Algomian granites.[1]

BORDER PHASES AND LOCAL VARIATIONS

In a belt about a mile in width around the batholith the granite shows a modification of its characteristic features; notably, the quartz "phenocrysts" disappear, quartz becomes less abundant, and in places the rock has a much larger per cent of dark minerals. The variation is not uniform, but is certainly so common along the north, east, and south sides as to make it proper to speak of a border phase. The outcrops have been described as granites, syenites, and diorites, but relatively few have plagioclase more calcic than oligoclase.[2] Only in a few small areas near the granite boundary are there porphyries with a groundmass finer than the normal granites.

The gradation from the main types to the border phase can be noted in many places, as, for example, in the southwest bay of Northern Light Lake. The quartz "phenocrysts" first become smaller than less numerous, and at that stage the texture seems to be equigranular granitoid. Still the rock has some quartz, and is a gran-

[1] Frank F. Grout, "Geology and Magnetite Deposits of Northern St. Louis County, Minnesota," *Minn. Geol. Survey Bull. 21* (1926), p. 34.

[2] *Minn. Geol. and Nat. Hist. Survey Final Rept.*, Vol. V, p. 308, calls a rock a diorite without definite determination of the feldspar.

ite. Some less acid phases occur locally in this zone. Another kind of gradation from the main granite to a more even-grained rock is through *schlieren*—described above as occurring near Saganaga Falls, but this was not at the border zone.

Locally, as on the north side of Cache Bay, the border phase is missing and the typical granite of the main mass is in contact with the greenstone.

The average granite of the border zone has about 40 per cent oligoclase, 25 per cent orthoclase or microcline, 20 per cent quartz,

FIG. 10.—Sheet structure in an even granitoid phase of Saganaga granite, on the most northerly island in the United States side of Saganaga Lake.

10 per cent of mafic minerals, mostly hornblende, but including more biotite than the central granite. The accessories and alteration products are much like those in the central area. Some secondary glaucophane indicates that there may be locally some rather alkaline phases. The ferromagnesian minerals are most significant. In places (e.g., Secs. 15 and 16, T. 65 N., R. 5 W., on Gull Lake) the hornblendes of the rock have many central cores of colorless pyroxene.[1] It seems likely that much of the hornblende is derived from augite, but the hornblende is so coarse and the rock so massive that it can hardly

[1] *Minn. Geol. and Nat. Hist. Survey Final Rept.*, Vol. V, p. 308, records a similar rock farther east in the same zone, near the outlet of North Lake.

be attributed to later metamorphism. The change is therefore believed to be deuteric. In several exposures there are also coarse biotite grains which seem to be primary or deuteric, along with hornblende, or in place of it.

On the whole the border granite has less quartz and more mafic minerals and is more sodic than the central granite of the batholith. It is believed that the more abundant quartz in the center is related to the occurrence of the quartz "phenocrysts." It may be that the border phase lacks them because the magma at an early stage was less siliceous, but it is also likely that the border solidified so soon that late siliceous residues did not permeate it.

About one-third of the area of the border zone has so little quartz that the rock is a syenite. This has the same differences from the Saganaga granite carried one step farther. Quartz finally disappears and hornblende increases to 30 per cent.

At several places in the border zone there are considerable areas of very dark rock, which have been variously interpreted. The dark color is due to abundant hornblende and low quartz and feldspars, the rocks grading through syenite and shonkinite to hornblendite (see Table III for the modes). Although there are clear exposures of the gradation from granite to hornblendite, there is also some hornblendite sharply outlined as inclusions in granite. Since the Keewatin greenstone near by might furnish some such hornblendite by contact action, it is not easy to determine whether the dark rocks result from alteration, assimilation, or differentiation. Quite possibly there may be hornblendic rocks of both sorts. The writer is inclined to consider most of the dark rocks as differentiates because of their association with a peculiar variety of shonkinite (Basswood type), which is known in other batholiths in Minnesota in such relations as to make it very certain that it is differentiated without foreign contamination.[1] It seems quite analogous to some occurrences of cognate xenoliths of highly hornblendic rocks in the granites of Finland.[2]

[1] Frank F. Grout, "Northern St. Louis County, Minnesota," *Minn. Geol. Survey Bull. 21* (1926), p. 38; I. S. Allison, "The Giants Range Batholith, Minnesota," *Jour. Geol.*, Vol. XXXIII (1925), pp. 498–99.

[2] Eskola, *op. cit.*, pp. 68–69, 75, and 86.

The most noteworthy area of shonkinite on Saganaga Lake is in Sec. 33, T. 67 N., R. 4 W., on the east end of an island and on some rocky islets just east of that, on the Canadian side of the boundary. The petrographic peculiarity is the poikilitic inclusion of abundant euhedral hornblende grains in much coarser acid feldspars; the weathering of the rocks produces white patches in a prevailingly dark mass (see Figs. 11 and 12). In the poikilitic rock oligoclase is

TABLE III

MEASURED MODES OF PHASES OF SAGANAGA GRANITE

	Quartz	Orthoclase	Plagioclase	Hornblende	Accessories
Central granites, 85–90 per cent of the mass...	43	10	42	5	.....
	35	12	48	4	1
	26	28	41	5	.....
	26	19	49	5	1
	19	23	51	7	.....
	22	29	42	5	2
	20	24	49	5	2
	14	31	45	9	1
	30	20	40	10	.....
Border granites.....	21	22	50	5	2
	20	65	10	0	5
	12	20	55	13	.....
	18	11	32	27	12
Border syenites.....	10	32	40	15	3
	5	25	45	20	5
	.....	7	80	8	5
Shonkinites.....	6	14	26	53	1
	3	8	22	65	2
Hornblendite.....	.....	5	2	93	.....

the chief feldspar, but in other shonkinites it may be orthoclase or a mixture. Dark rocks occur in smaller masses in one or two other places far inside the granite, but are much more common near the north and south borders.

The border zone of the batholith seems in many cases to be more affected by metamorphism than the massive core, possibly because the contact formations are less resistant and move more freely along the outside of the solid granite core. Such rocks are found at the northeastermost bay of Saganaga Lake, and north of Bridge Bay of North Lake. They show a moderate amount of granu-

lation, and the dark minerals are smeared out into streaks at the ends, but most of the features of the granite border zone remain.

As noted above, much of the border rock is trachitoid in texture without the least sign of later metamorphism dynamically.

The equigranular granites and darker rocks so characteristic of the border zone of the batholith are not limited to that zone. In fact, the shonkinite (Basswood type) referred to above is not far from the

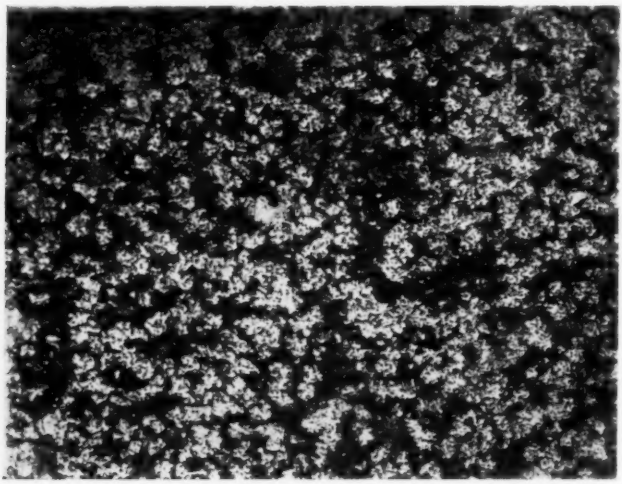

FIG. 11.—The spotted shonkinite (Basswood type), of Saganaga Lake; natural size.

center of the area and seems to be related to a belt of granite without quartz "phenocrysts," running a little irregularly from Sec. 4, T. 66 N., R. 4 W., to Sec. 23, T. 66 N., R. 5 W. This belt may be a remnant of a border phase, if before erosion some roof pendant of the batholith hung close above; but this is purely speculation, while the facts are clear that there are irregular masses near the center that much resemble those more largely developed along the border. Even-grained granites and syenites occur also in the satellitic stocks and dikes near the granite contact.

Another noteworthy phase of the shonkinite outcrops on the east side of a point in the SE. $\frac{1}{4}$ of Sec. 22, T. 66 N., R. 5 W. The patch

is so local as to suggest an inclusion, but there are gradations to typical Saganaga granite. Much of the dark rock contains quartz "phenocrysts" exactly such as occur in the typical granite near by, furnishing a particularly strong indication that the dark rocks are genetically related to the main granite of the batholith.

One of the rocks most often mentioned in earlier reports is the red granite with fluorite on the northeast side of an island in Sec.

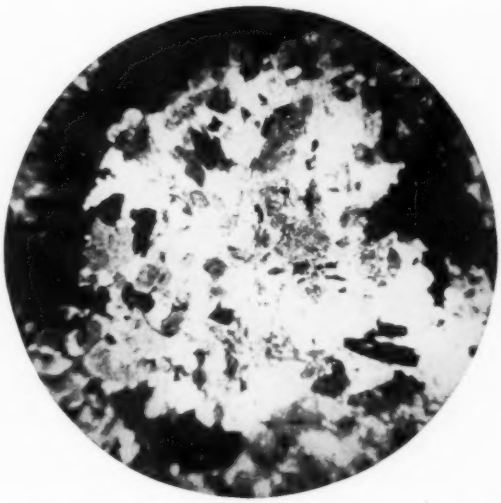

FIG. 12.—Thin section of shonkinite (Basswood type), showing scattered euhedral hornblende in feldspar. ×30.

14, T. 66 N., R. 5 W. This is found mostly near a fluorite pegmatite dike (prospected for gold), and in the field it is difficult to determine whether the fluorite of the pegmatite was segregated from the mother-liquor of the granite near by, or the fluorite of the pegmatite magma was brought in from a distant source and permeated the granite walls. A study of the thin section shows in addition to some large grains of fluorite in quartz some widespread replacements of the orthoclase and albite by granular fluorite, and numerous veinlets of fluorite and quartz. It is therefore believed that the fluorite is introduced from the pegmatite, though probably the pegmatite itself

is closely related to the granite of the same batholith; it is perhaps on the dividing line between the deuteric and later introductions.[1] The ferro-magnesian minerals of the granite are now represented only by limonite which seems to be weathered from pyrite.

The variation in these several phases is chiefly in the abundance of hornblende, but the chemical compositions are also noteworthy (Table II).

These rocks containing hornblende have very abnormative modes. The norm, not showing hornblende, has much diopside and hypersthene; and the calcium and aluminum of the hornblende greatly increase the anorthite calculated in the norm.

DIKES IN AND NEAR THE GRANITE

Cutting the Saganaga granite are dikes of aplite and pegmatite in very small volume; dikes of later diabase, probably Keweenawan and of no special peculiarity; and a few lamprophyr dikes of considerable extent. In the wall rocks near the granite is a complex of various kinds of dikes that seem to be more or less closely related to the granite.

The lamprophyrs are well illustrated by a kersantite dike some 20–30 feet wide which appears at intervals from Sea Gull River north to the boundary. In the field the rock is very dark, but the feldspar is red and unevenly distributed. The texture is granitoid, and the absence of chilled borders suggests that the dike was formed before the granite around it was cold. A good exposure on islands in Sec. 7, T. 66 N., R. 4 W. shows biotite and augite about equal in amount to albite-oligoclase. There is a great deal of secondary chlorite, and this has associated with it a surprising amount of perovskite. As in most lamprophyrs there is some potash feldspar and potash in the biotite; also some alteration to calcite. Magnetite and ilmenite are abundant, pyrite only in traces. Some rounded pseudomorphs indicate that olivine may once have been present.

The dikes in the greenstone walls of the batholith are of interest chiefly in showing the complexity of batholithic action. They are of great petrographic variety and intricate cross-cutting relationships,

[1] Old reports describe the fluorite simply as "scattered grains" (see *Final Rept.*, Vol. IV, pp. 322–23).

but all are so situated near the edge of the granite as to indicate their relation to the main magma. This relationship is not proved, however, by any dike of such rock as the main Saganaga granite with quartz "phenocrysts" (Fig. 6). The strongest suggestion of that phase in a dike is on the north side of Cache Bay where there is no notable development of border-phase granite. Here is a porphyry dike with true phenocrysts of quartz about the size of the quartz

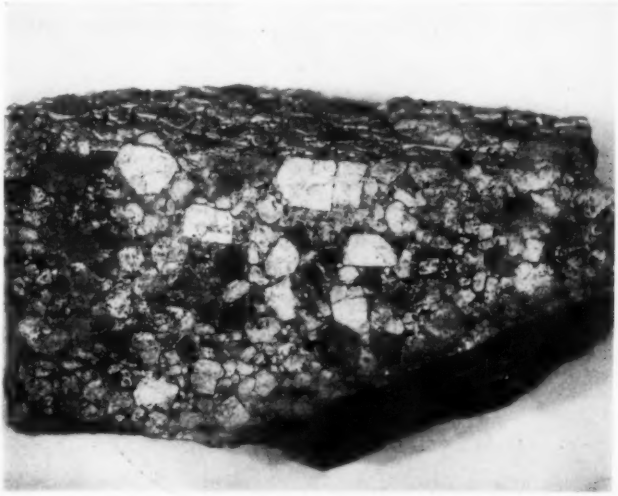

FIG. 13.—Granite porphyry from a dike north of Cache Bay. White crystals, albite; dark gray, quartz. Natural size.

patches in the granite (Figs. 13 and 14). Some of the phenocrysts are aggregates—glomero-phenocrysts like the quartz of the main granite. It is their early crystallization to large grains which suggests a relation to the granite. The feldspar in this dike is almost wholly albite (see col. 13 of Table II).

The more abundant dikes in the greenstone are quite naturally those which resemble the border phases of the granite. A few such dikes also occur in the gneiss on the northeast side of the batholith (see location 4, Fig. 2). Most of these dikes in greenstone are granite with hornblende or biotite or both, and they have normal textures,

not even the border being chilled. They grade into syenite, shonkinite, and probably diorite, and it is said that they get darker as traced farther into the greenstone from the main border of the granite.[1] Dynamic effects were probably greater in the greenstone than in the granite of the main mass, and the dikes in the greenstone show faulted and bent feldspars.

Besides the dikes of granite and its gradation to more basic phases, there are aplites and porphyries. These cut the granite

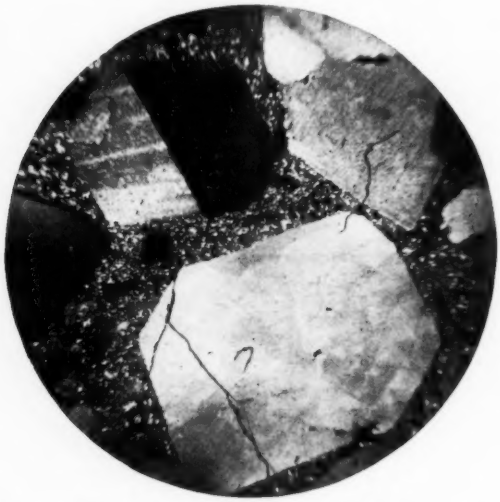

FIG. 14.—Thin section of dike rock shown in Figure 13. ×15

dikes,[2] but in most of the complex the dikes of different sorts do not cut each other.

In summary, acid dikes intruded greenstone at least three times, but all three may be within the time of one batholithic invasion. In only one place is there a suggestion of later acid igneous intrusives—some porphyry intrudes slate that appears to be younger than the batholith, on the hill slope north of Gunflint Lake.

[1] U. S. Grant, *Minn. Geol. and Nat. Hist. Survey Final Rept.*, Vol. IV, p. 467.

[2] *Ibid.*, Vol. XX (1893), p. 83, and *Final Rept.*, Vol. IV, p. 467.

INCLUSIONS

Inclusions in the Saganaga batholith are much less numerous and varied than those in the older gneiss northeast, and those in the Giants Range and Vermilion batholiths. Those found are chiefly dark masses made up largely of hornblende,[1] and it is not easy to determine whether they are altered Keewatin greenstone or some hornblendic phase of the batholith or both. Alexander Winchell described a closely clustered mass of inclusions on an island which he called Wonder Island, about a mile northeast of Saganaga Falls; and then having found the shonkinite-hornblendite (described above as a phase of the batholith) on a larger island in the next square mile west (Sec. 33, T. 66 N., R. 4 W.), he concluded that this large dark mass furnished the inclusions on Wonder Island.[2] This seems a reasonable interpretation, and it is believed that most of the dark patches are cognate xenoliths.[3] They are widely scattered but not abundant. Some shonkinite, both in large areas and in inclusions in granite, has smaller inclusions of hornblendite, thus clearly showing the age relations of the three rocks.

DIFFERENTIATION

It was concluded in the foregoing discussion that the dark rocks of the Saganaga batholith probably developed in the batholith without much contamination. While this conclusion is based on the slender evidence of a peculiar petrographic feature—the shonkinite of Basswood type which has been developed in another batholith where contamination is quite certainly lacking—it nevertheless leads one into no difficult or surprising consequences (see Fig. 15 and Table III).

The course of evolution of the magma can be traced only in part, but seems likely to have begun with a basaltic composition—at least one from which rocks as basic as hornblendite could be formed. The hornblendite, though low in alkalies, is not very different from basalt

[1] A. Winchell, *Minn. Geol. and Nat. Hist. Survey Sixteenth Ann. Rept.*, p. 222; in the field, supposed the dark mineral was augite.

[2] *Ibid.*, p. 226. He described them as augite rocks in the field.

[3] Winchell inferred they were boulders in a conglomerate that had an igneous matrix, but his description is accurate.

in composition and might easily be attributed to the reaction of a hydrous late stage of the magma on cognate xenoliths of gabbro.

From such an original the magma yielded in succession hornblendite (possibly a little diorite), shonkinite, syenite, granite, and later dikes, aplite, pegmatite, and possibly kersantite. The kersantite seems less related to the series than the others but is perhaps no more distinct than lamprophyrs and late basic dikes in other districts.[1] The larger masses of rock intermediate between granite and hornblendite are no doubt phases cooled at an intermediate time.

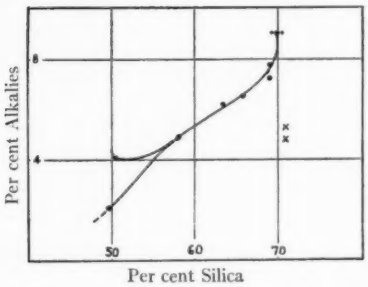

FIG. 15.—Curve of variation of the Saganaga batholith in silica and alkalies. The spots represent rocks analyzed. The crosses show the composition of the main rocks of the older gneiss on Northern Light Lake.

At a late stage the magma, however, must have been so different in composition from the early minerals that many reactions occurred. It is likely that much early augite recrystallized to hornblende and that the large quartz aggregates formed only after the mineralizers were considerably concentrated. These late acid fluids may have reacted also on some of the early basic rocks to produce intermediate rocks much like those formed at intermediate time. Such reactions, however, probably occurred chiefly in fragments of the early phases, stoped into the late magma. Few such fragments are found, and the specific gravities indicate that the early border phases would rapidly have sunk if detached as xenoliths in the later magma. The border and early phases have a density about 2.70–3.00 (greenstone averages about 2.975), while the granite of the main mass has a density of 2.657.

It should be noted that the quartz "phenocrysts" were seen in one of the dark xenoliths, but certainly such a development is not the general rule. In the granite large quartzes appear only where silica constitutes over 66 per cent of the rock.

[1] J. E. Spurr, "Basic Dikes in Magmatic Vein Sequences," *Bull. Geol. Soc. America*, Vol. XXXVI (1925), pp. 545–82.

The sequence just described is based on the inclusion of fragments of the earlier rocks in the later ones, reinforced by the general idea that basaltic rocks would solidify at higher temperatures and therefore earlier than granites.

The same general sequence is found, however, with some irregularity and minor reversals, from the sides to center of the mass. Probably the whole width of the area was once occupied by such magma as formed the early basic border rocks; but after the border

TABLE IV

SHOWING SIMILARITY OF COMPOSITION OF HORNBLENDITE AND BASALT

	Hornblendite	Average Basalt (Daly)
SiO_2	49.81	49.06
Al_2O_3	11.43	15.70
Fe_2O_3	2.77	5.38
FeO	7.22	6.37
MgO	12.18	6.17
CaO	13.14	8.95
Na_2O	1.10	3.11
K_2O	.91	1.52
H_2O+	1.58	1.62
H_2O-	.14	(MnO) .31
TiO_2	.35	1.36
	100.63	100.00*

* Includes $.45P_2O_5$

solidified the processes of evolution in the magma left 85 per cent in the central part to solidify as granite.

If this evolution is independent of additions and subtractions, the result implies that an enormous amount of more basic rock formed in some other part of the chamber—probably below the granite. The depth of the chamber must have been very great.

A progressive but slightly irregular change in the ratio of potash to soda is indicated by Table V.

This is probably a common sequence in the evolution of batholiths. It is prominent in the much younger Vermilion batholith where the ratio $K_2O:Na_2O$ varies from .4 in some border rocks to above 1.0 in the central parts.[1] Some stocks at Rainy Lake show a

[1] Frank F. Grout, "The Vermilion Batholith," *Jour. Geol.*, Vol. XXXIII (1925), pp. 467–87.

somewhat similar increase in potash in the central syenite,[1] but there may be others there that are highly sodic throughout. The mineralogic indications of such a series are reported from a number of more distant batholiths, and analyses make the case definite for a batholith described by Eskola from Finland.[2]

The general character of this series of differentiation products is thus nothing exceptional. Possibly more batholiths have gabbro-diorite series than have hornblendite-shonkinite series, as basic early phases, but neither need be considered surprising. Chemically the two series are not very different.

TABLE V

THE SODA AND POTASH FROM SIDE TO CENTER OF THE SAGANAGA GRANITE; AND IN OLDER GNEISS

	Na_2O	K_2O	RATIO K_2O:Na_2O
Northern Light Lake, Earlier Batholith (Average of 2)	4.20	.88	.21
Saganaga granite:			
Porphyry dike in greenstone (1)	4.49	.94	.21
Border syenite (1)	6.47	1.26	.20
Border granite (average of 2)	4.28	2.05	.48
Shonkinite and hornblendite (av. of 3)	2.39	1.26	.53
Main granite (average of 4)	4.16	2.60	.62
Late fluorite granite (1)	5.54	3.59	.65

The most closely related series known to the writer is that of the neighboring Giants Range granite of Algomian age.[3] Only the most detailed study shows any differences in the two petrographic series. Other similar series occur in widely scattered places.[4] A Paleozoic example is the Cortlandt series;[5] and Mesozoic and Cenozoic exam-

[1] Lawson, *op. cit.*, p. 91; I. H. Cram, thesis, University of Minnesota.

[2] P. Eskola, *op. cit.*, No. 40, p. 59.

[3] I. S. Allison, "The Giants Range Batholith of Minnesota," *Jour. Geol.*, Vol. XXXIII (1925), pp. 498–99. Some of the analyses reported in that paper show too much soda and too little potash in the late phases.

[4] A summary is given by Frank F. Grout, "A Graphic Study of Igneous Rock Series," *Bull. Geol. Soc. America*, Vol. XXXIII (1922), pp. 617–38, and Fig. 3.

[5] G. S. Rogers, *Annals of N.Y. Acad. Sci.*, Vol. XXI (1911), pp. 61–63.

ples are found in the Cordillera.[1] There is nothing about the pre-Cambrian granites whether early Laurentian or as late as Keweenawan to indicate that they formed from a different source or by a different method from later granites. The Laurentian batholith resembles the later batholiths in composition, variation, and structural setting.

[1] See, e.g., R. A. Daly, "Geology of the North American Cordillera at the 49th parallel," *Chief Astronomer Rept. 6* (1913), pp. 455–58 and 533–39.

THE AGE AND NOMENCLATURE OF THE ROME ("WATAUGA") FORMATION OF THE APPALACHIAN VALLEY[1]

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ABSTRACT

Much confusion of nomenclature exists concerning the proper name to be applied to the stratigraphic unit under consideration, since at least eight different names have been used by various authors. An attempt is here made to co-ordinate these different terms and to establish a name which will be in accord with modern usage and will eliminate those terms which are inappropriate.

A complete list of the known fossils of this formation is compiled, and the bearing of these forms on the age of the unit is discussed.

The Watauga shale[2] of Virginia and Tennessee takes its name from the Watauga River in northeastern Tennessee which drains large areas of its outcrop.

The formation is part of a lithologic unit which extends from Alabama, through Georgia, North Carolina, eastern Tennessee, western Virginia, eastern West Virginia, and western Maryland into the Cumberland Valley of Pennsylvania. It is typically a series of sandy shales or limestones interbedded with rusty-brown or variegated shales. The formation changes greatly along its strike, and its most conspicuous colors are reds and purples, so that it is often described as a "red or purple shale series." Green and yellowish shales occur in equal volume with the reddish shales, but are seldom so striking. Mottled-blue limestones and dolomites alternate with the shale bands, especially in the lower part of the formation, and these limy beds often contain thin chert zones. Calcareous, rusty-weathering sandstone members are also common. None of the beds withstands decay well, and the calcareous members readily dissolve,

[1] Published with the permission of the Virginia Geological Survey, and including data on Roanoke County, Virginia, to be published in an early bulletin on that area by the Geological Survey of the Virginia State Commission on Conservation and Development.

The author is greatly indebted to Dr. Charles Butts, of the U.S. Geological Survey, who read the manuscript and made important corrections and additions.

[2] Arthur Keith, *U.S. Geol. Survey Geol. Atlas, Cranberry Folio 90* (1903), p. 3.

leaving the shales and sandstones to crumble and disintegrate. Many of the beds show evidence of shallow-water origin, occasionally containing ripple-marks, sun-cracks, and cross-bedding. The formation weathers deeply to form a compact dry clay, banded in colors of red, purple, and buff. The soils are not especially fertile, but have been extensively cultivated because of their accessibility, and are hence more productive than are similar soils less favorably situated.

Throughout most of its outcrop this formation is found along the southern edge of the Great Valley in a comparatively narrow belt just west of the Blue Ridge foothills. Its complicated structure in this belt shows that as a weak formation it has been intimately crumpled and folded in the deformation of the region. Other outcrops of the formation also occur in disconnected belts along the northwestern side of the valley. The formation has been so intensively folded that accurate determinations of its thickness are difficult to obtain. It is about 1,000 feet thick in Alabama, 700 feet thick in Georgia, from 500 to 3,000 feet thick in eastern Tennessee, more than 1,000 feet thick in western Virginia where its base is not exposed, and about 1,200 feet thick in the Cumberland Valley of Pennsylvania.

In the southwestern part of its belt of outcrop, the equivalent of the Watauga shale has long been called the "Rome formation." This name was applied in 1891 by C. W. Hayes[1] from Rome, Floyd County, Georgia. Publication of the name Rome for this series of rocks was antedated by publication of the names Montevallo or Choccolocco, terms simultaneously introduced for the series under discussion by the Alabama Geological Survey[2] in 1890. Since these earlier names never gained much currency, while the name Rome has been used in so many publications of the United States Geological Survey, it appears best to disregard their slight priority over Rome, and to abandon them as has been done by the Alabama Geological Survey. The Rome formation possesses the same lithological characteristics as the Watauga shale, and occupies the same stratigraphic interval.

[1] "The Overthrust Faults of the Southern Appalachians," *Bull. Geol. Soc. Amer.*, Vol. II (1891), p. 143.

[2] E. A. Smith, *Alabama Geol. Survey Report on the Cahaba Coal Field* (1890), p. 148.

To this formation in the northeastern part of its belt of outcrop the name Waynesboro has been applied by Stose.[1] At its type locality, the Waynesboro shale is a series of hard, siliceous purple shales and flaggy calcareous sandstones outcropping near Waynesboro, Pennsylvania. The Waynesboro is the stratigraphic equivalent of the Watauga shale, and it is possible to trace the two formations into each other along their outcrops in the field.

Several other names have also been applied to the Rome ("Watauga")-Waynesboro horizon. In 1905, H. D. Campbell[2] designated the same unit the "Buena Vista shales," from their exposure along the James River at Buena Vista in west-central Virginia. The name Buena Vista, however, had already been used for a subdivision of Mississippian rocks in Ohio.[3] Prior to 1904, this Mississippian usage had been abandoned, but was revived in 1904 by Prosser[4] who used it for the lower member of the Cuyahoga group in Ohio. Because of this earlier application, as pointed out by Prosser[5] in 1906, the term Buena Vista was not available for the Cambrian shales of Virginia as used by H. D. Campbell.

In 1899, M. R. Campbell[6] applied in southwestern Virginia the name "Russell formation" to a series of thin alternating bands of shale, sandstone, and limestone, of various hues but generally colored with shades of red or brown. This series lies directly below the Great Valley limestone series, and represents the Watauga shale together with possibly the upper part of the Shady dolomite or equivalent horizons which normally underlie the Watauga shale. The term Russell has often been applied in southwestern Virginia to the equivalent of the Wautauga in the belts of outcrops along the northwestern

[1] G. W. Stose, "The Sedimentary Rocks of South Mountain, Pa.," *Jour. Geol.*, Vol. XIV (1906), pp. 208–9.

[2] "Cambro-Ordovician Limestones of the Middle Portion of the Valley of Virginia," *Amer. Jour. Sci.* (4th ser., 1905), Vol. XX, p. 445.

[3] Edward Orton, "Report on the Third District," *Ohio Geol. Survey Report 2*, Part I (1874), p. 624.

[4] Charles Prosser, "The Waverly Formations of Central Ohio," *Amer. Geologist*, Vol. XXXIV (1904), pp. 341–42.

[5] Charles Prosser, "Notes on the Use of the Term Buena Vista as the Name of a Geological Terrain," *Amer. Jour. Sci.* (4th ser., 1906), Vol. XXI, pp. 181–82.

[6] *U.S. Geol. Survey Geol. Atlas, Bristol Folio 59* (1899), p. 3.

side of the Appalachian Valley where beds lower than the Watauga are not known to be exposed. The "Russell formation," as so defined, has about the same thickness as the true Watauga shale, and it is improbable that much if any of the Shady dolomite is included.

At an earlier date than his designation of the name "Russell formation," M. R. Campbell[1] called the same formation the "Graysonton formation" at its exposure in Montgomery and Pulaski counties in Virginia. Apparently this name was abandoned in favor of Russell, for no further reference to Graysonton has been found by the writer.

The following names therefore have been variously applied to the formation under discussion:

Montevallo or Choccolocco shale [Smith, 1890]
Rome sandstone [later Rome formation] [Hayes, 1891]
Graysonton formation [M. R. Campbell, 1894]
Russell formation [M. R. Campbell, 1899]
Watauga shale [Keith, 1903]
Buena Vista shale [H. D. Campbell, 1905]
Waynesboro shale [Stose, 1906]

It would appear that most of these names should be put into synonomy in order to avoid confusion in stratigraphic description and correlation. As has already been mentioned, many of the foregoing names are now discarded for one reason or another. Montevallo, Choccolocco, Graysonton, and Buena Vista will not be found in current geologic literature as accepted names for the unit herein described. The Waynesboro shale is the exact equivalent of the Watauga shale, and its name may be discarded in favor of Watauga, which is of earlier application. The Russell formation of southwestern Virginia has already been identified with the Rome formation of Tennessee, and its name has been dropped from current usage.

The United States Geological Survey has recently decided to apply the term "Rome formation" to all of the southernmost outcrops of this unit, and Watauga and Rome, respectively, to its southeastern and northwestern outcrops along the Great Valley in Tennessee and Virginia. The name Watauga is retained because of its

[1] "Paleozoic Overlaps in Montgomery and Pulaski Counties, Virginia," *Bull. Geol. Soc. Amer.*, Vol. V (1894), p. 175.

long use in the southeastern belt in Virginia and Tennessee, and because it is believed there is a possibility that the two are not equivalent. This belief rests upon the fact that along the southeastern side of the valley the formation overlies the Shady dolomite and its base is therefore known, whereas on the northwestern side of the valley the bottom of the formation is not exposed, and therefore may not include horizons as old as the basal beds of the formation on the southeastern side. Although the base of the formation has not been discovered along the northwest side of the Valley, yet in the type locality of the Rome formation near Rome, Georgia, and in northeast Alabama, the Shady has been found below the undoubted Rome formation, and on this evidence there is no essential difference in stratigraphic position between the Rome and the Watauga.

Dr. Charles Butts[1] in a recent paper and by personal communication to the writer has recorded his preference for the name Rome, and would make all other names synonyms of this term. This is on the ground that Rome has several years' priority over Watauga, and that there is no warrant for using Watauga except on the remote possibility that the two are not substantially equivalent. The writer feels that this sudden exclusion of the term Watauga (which is now well established in geologic literature) would make for confusion rather than precision at the present time, and therefore suggests that the two names be connected, for the time being at least, in the current designation of this unit. The hyphenated term Rome-Watauga does not meet with the approval of the Committee on Geologic Names of the United States Geological Survey, and no doubt would help the situation very little, since in itself and in its adoption there would be an element of confusion.

If the two names are really synonyms as is here concluded, one of them should be dropped, and on the basis of priority and usage the proper name should be Rome and the name to be dropped should be Watauga. The confusion or inconvenience arising where only Watauga has been used may be largely obviated by the temporary expedient of putting the abandoned name in quotes and parentheses after the adopted name, thus: Rome ("Watauga"). This suggestion

[1] "Variations in Appalachian Stratigraphy," *Jour. Wash. Acad. Sci.*, Vol. XVIII, No. 13 (1928), p. 360.

has the sanction of the United States Geological Survey.[1] The writer, therefore, suggests that this proposed usage be adopted in coming papers involving this stratigraphic unit for prominent places such as headings and map legends, until that time when the geologic public no longer needs the historical bridge across the change in nomenclature, and the name Rome alone may be used.

It is obvious that a fine and somewhat important point in stratigraphic nomenclature is here involved. In the earlier days of areal geological mapping, a number of names was often applied to isolated outcrops of rocks in areas which were some distance apart and in which exact correlations with units previously described and named had not been established. This of course was a justifiable procedure, since it is better to apply temporarily a new name rather than to be inexact or careless in the application of an old one. However, when identity of the units variously named has been established (as in the present case), one of the names should be retained at the expense of the others, which should be dropped even at the risk of temporary inconvenience. In biology, selection of the proper name is based rigidly upon the law of priority of designation, and in only a few cases has exception been made to this rule. Stratigraphic nomenclature, however, by common consent is not bound solely to the law of priority of designation, but takes also into consideration the important fact of priority of adopted usage. In other words, the stratigrapher is not forced to reject a name which has wide currency in geologic literature in favor of an obscure term, even though the latter may have been the first to be applied.

The case in question is an admirable illustration of the essential difference between stratigraphic and biologic practice of nomenclature, where the first name to be applied to this unit (Montevallo) is properly disregarded in favor of a later but better-known term (Rome), in accord with the idea of priority of adopted usage.

Fossils are locally scarce in the Rome ("Watauga") formation, and have seldom been carefully sought for or adequately studied, so that data requisite for satisfactory determination of its age have never been assembled.

[1] Personal communication from Dr. T. W. Stanton, chairman, Committee on Geologic Names.

The Russell formation is described by Campbell[1] as containing a typical *Olenellus* fauna on Copper Creek, Scott County, Virginia. Dr. Charles Butts has informed the writer that he found

Olenellus in the Rome ("Russell") in two places on the northwest side of the Valley in Virginia. It occurs in ferruginous sandstones one-half mile west of Clinchport in Scott County, where the horizon is about 300 feet below the top of the Rome; and about a mile southeast of Cleveland in Russell County, where the horizon is not well known, but where it seems to be high in the Rome. Collections in the first belt of Rome north of Cresswell (see Bristol folio) show Ptychoparian forms at several horizons down to the lowest beds exposed next to the fault where the Rome is thrust up into contact with the Moccasin limestone. The thickness here from the lowest bed of rusty sandy limestone with a Ptychoparian form to the highest red shale is about 1,250 feet, and to the top of fairly continuous red shales is about 1,100 feet. At about 1,150 feet above the bottom occurs *Dolichometopus productus*, which is universally assigned to the Middle Cambrian. Above it are two thin layers of red shale, the highest about 65 feet above. *Dolichometopus productus* occurs in the section southeast of Cleveland mentioned above, at what I regard as the same horizon, but with no red shale above. The horizon of *Olenellus* should not be far below in that section.[2]

In Alabama, the Rome formation contains a number of recognizable forms, mainly trilobites and brachiopods. Walcott[3] records the following forms from near Helena, Shelby County, Alabama:

Micromitra (Paterina) major
Micromitra (Paterina) williardi
Obolus smithi
Wimanella shelbyensis
Paedumias transitans
Wanneria halli
Agraulos?
Hyolithes

To this list and from the same general locality Butts has[4] added *Olenellus thompsoni*. These fossils were found within 300–500 feet of the local top of the Rome formation. Walcott[5] also records the occurrence of a form provisionally identified as *Acrotreta kutorgai?* from shales just above the *Olenellus* zone north of Montevallo, Alabama.

[1] M. R. Campbell, *U.S. Geol. Survey Geol. Atlas, Estillville Folio 12* (1894), p. 5.

[2] Personal communication.

[3] C. D. Walcott, "Cambrian Brachiopoda," *U.S. Geol. Survey Monograph 51*, Part I (1912), p. 206.

[4] Charles Butts, *U.S. Geol. Survey Geol. Atlas, Bessemer-Vandiver Folio 221* (1927), pp. 2–3.

[5] *Op. cit.*, p. 224.

In Greene County, Tennessee, the Rome formation contains many "tracks, trails and impressions," and was considered by Keith[1] to be of Lower Cambrian age on the basis of these markings. From Hawkins, Roane, and Knox counties in Tennessee, Walcott[2] lists the following trilobites from the Rome formation:

Ptychoparia sp. undet.
Bathyuriscus bantius
Dolichometopus productus

On page 147 of Walcott's *Cambrian Brachiopoda* (*U.S. Geol. Survey Monograph 51* [1912]) is given a considerable list of brachiopods from the upper part of the "Rome formation." This list is largely composed of forms from Knox, Hawkins, and Roane counties, Tennessee, and from Floyd County, Georgia, and the forms listed are of Middle and Upper Cambrian age. These brachiopods are identical with those of the higher Conesauga and Rogersville shales, and it is exceedingly improbable that the fossils in this list were found in the true Rome formation of Tennessee or Georgia, but were taken from later beds whose lithology was similar to and confused with the actual Rome formation. In the present discussion of the age and fauna of the Rome ("Watauga") these forms will be omitted on the ground that every evidence points toward a misidentification of their exact horizons, and that they should be correctly listed from beds higher than the unit under consideration.

The Waynesboro shale of Pennsylvania is reported by Stose[3] to contain a few poorly preserved shells, two of which were identified as *Obolus* (*Lingulella*) species undetermined. The fossils were obtained from a sandy shale at the very top of the formation, and suggest Acadian (Middle Cambrian) age, but are not conclusive proof of this age. Butts[4] reports that a brachiopod provisionally identified as *Linnarssonia* is abundant in a thin layer of these shales at Waynesboro, Virginia.

[1] Arthur Keith, *U.S. Geol. Survey Geol. Atlas, Greeneville Folio 118* (1905), p. 4.

[2] C. D. Walcott, "Cambrian Trilobites, III," *Smithsonian Misc. Coll.*, Vol. LXIV, No. 5 (1916), pp. 336–37, 371.

[3] G. W. Stose, *U.S. Geol. Survey Geol. Atlas, Mercersburg-Chambersburg Folio 170* (1909), p. 5.

[4] Personal communication.

Walcott[1] in 1891 found several specimens of a species of *Ptychoparia* in the "Buena Vista shales" near Natural Bridge in Virginia, and described the form as being very closely related to *Ptychoparia* from the Middle Cambrian beds of Tennessee.

Bassler[2] has recorded the presence of *Olenellus* from the Watauga shales of Roanoke County, Virginia. These fossils were found by S. L. Powell near Salem, Virginia. A personal communication to the writer from Powell gives the location of this find about 2 miles east of Salem along Mason's Creek. Powell states that the fossils were found in a ledge of Watauga shale, and that he secured several specimens, mostly cephala, although one complete individual was found. The writer made a cursory examination of this ledge during the summer of 1927, but obtained no additional specimens. Professor R. J. Holden, of Blacksburg, Virginia, showed the writer several specimens of *Olenellus thompsoni* taken from red and purple shales of unknown age in a cut of the Norfolk and Western Railway about 1 mile south of Blue Ridge Springs, Botetourt County, Virginia. These shales were later identified by the writer as Rome ("Watauga") shales.

During the summers of 1927 and 1928, while completing the field work of a report on the geology of the Roanoke area for the Virginia Geological Survey, the writer discovered three new localities for *Olenellus* in the Rome ("Watauga") shales of west-central Virginia. The most important of these new localities is along the road leading eastward over Porter's Mountain from the Roanoke-Lynchburg Highway, $1\frac{1}{2}$ mile south of Blue Ridge Springs, Botetourt County, Virginia. The fossils were found along the north side of the road in a low bank $\frac{1}{8}$ mile east of the road forks. A large number of specimens were collected from a fine-grained, gray-brown clay shale which is soft and poorly consolidated. The fossils were abundantly scattered through a few very thin shale laminae, and consisted largely of detached cephala and pygidia which were but slightly distorted. A few specimens showing thoracic segments were discovered, and

[1] C. D. Walcott, "Notes on the Cambrian Rocks of Virginia and the Southern Appalachians," *Amer. Jour. Sci.* (3d ser., 1892), Vol. LXIV, p. 52.

[2] R. S. Bassler, "Cement Resources of Virginia West of the Blue Ridge," *Virginia Geol. Survey Bull. II-A* (1909), p. 102.

two entire fossils were secured. The horizon of these trilobites appears to be below the middle of the Rome ("Watauga") formation, and is probably near the base of the formation. The species have been identified as *Olenellus thompsoni*, which is generally accepted as of Lower Cambrian age.

Similar specimens of the same genus of trilobites were found in western Roanoke County about 3 miles southeast of Glenvar, and 3 miles due east of the Roanoke River along the road leading up the valley of Dry Branch. This locality is over 30 miles farther southwest than the locality previously mentioned, but in the same outcrop and in strike with it. These specimens were found in red and buff shales, and in preservation and occurrence were entirely similar to those described above. At a third locality about ½ mile northwest of Cave Spring, Roanoke County, Virginia, a single cephalon of *Olenellus* was discovered in apparently the same horizon. *Cryptozoon* has likewise been found in the dolomitic members of the Rome ("Watauga") formation in the same general area.

The following list contains the known fauna of the Rome ("Watauga") formation with the formational name under which each form was described, together with the locality:

Acrotreta kutorgai?. north of Montevallo, Ala. [Rome]
Linnarssonia sp.?, near Waynesboro, Va. [Waynesboro]
Micromitra (*Paterina*) *major*, near Helena, Ala. [Rome]
Micromitra (*Paterina*) *williardi*, near Helena, Ala. [Rome]
Obolus smithi, near Helena, Ala. [Rome]
Obolus sp. undet., southern Pennsylvania [Waynesboro]
Wimanella shelbyensis, near Helena, Ala. [Rome]
Hyolithes sp., near Helena, Ala. [Rome]
Cryptozoon sp., southwest Virginia [Watauga]
Agraulos?, near Helena, Ala. [Rome]
Bathyuriscus bantius, Hawkins, Roane, and Knox Co., Tenn. [Rome]
Dolichometopus productus, near Cresswell, Scott Co., Va. [Rome]
Dolichometopus productus, Hawkins County, and near Knoxville, Tenn. [Rome]
Olenellus thompsoni, two localities in Scott County, Va. [Rome]
Olenellus thompsoni, five localities in and near Roanoke County, Va. [Watauga]
Olenellus thompsoni, near Helena, Ala. [Rome]
Olenellus thompsoni, near Montevallo, Ala. [Rome]

Ptychoparia sp. undet., near Natural Bridge, Va. [Buena Vista]
Ptychoparia sp. undet., Hawkins County, and near Knoxville, Tenn. [Rome]
Ptychoparia sp. undet., near Cresswell, Scott Co., Va. [Rome]
Paedumias transitans, near Helena, Ala. [Rome]
Wanneria halli, near Helena, Ala. [Rome]
Tracks, trails, and impressions, Greene Co., Tenn. [Rome]

Of the foregoing list the most abundant and diagnostic fossil form is *Olenellus thompsoni*, which has been found in this formation at nine scattered localities throughout the southern Appalachians, and at various horizons within the unit. According to general usage, *Olenellus* is a Lower Cambrian fossil, and by this criterion that part of the Rome ("Watauga") formation which contains *Olenellus* is of Lower Cambrian age. Since *Olenellus* is found up to within 300 feet of the local top of the formation, it appears that at least the major part of the formation is Lower Cambrian. The presence of Ptychoparian forms in association with *Olenellus* and even below the *Olenellus* horizon has no weight as determinative between Lower and Middle Cambrian, since the two trilobites are commonly associated in the same horizons in the Rocky Mountain sections.

That the extreme upper part of the Rome ("Watauga") is Lower Cambrian has not definitely been established, and the possibility that it is of Middle Cambrian age must be considered. At present the evidence is insufficient to establish this point, so that the Rome ("Watauga") formation is herein considered to be largely Lower Cambrian in age, but possibly containing Middle Cambrian equivalents in its extreme upper part. It should be observed at this point that Ulrich considers the formation to be entirely Middle Cambrian based upon the Rocky Mountain standard. The writer cannot concur with this interpretation in view of the general acceptance of *Olenellus* as a Lower Cambrian form.

WAVE-CUT PLATFORMS IN HAWAII

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ABSTRACT

Davis considers that the submarine banks of the leeward section of the Hawaiian Archipelago consist of considerable thicknesses of reef limestone and lagoon-floor beds deposited on subsiding volcanic basements. Many others believe that they are wave-cut platforms developed under conditions of relative stability, and that they have little detrital material over their central parts but thicker accumulations around their margins. Examples of wide, wave-cut benches in the windward section of Hawaii are described as favoring this second hypothesis.

In his recent publications on coral reefs, Davis[1] has stated that the islands of the Hawaiian Archipelago, particularly those of its leeward section, present evidence favoring the subsidence theory of the origin of coral reefs. According to Davis, the leeward group consists of 5 more or less imperfect bank atolls (Maro, Dowsett, Lisiansky, Midway, and Kure); 8 banks from 10 to 20 miles across, from which no reefs rise to the surface, and 1 bank of intermediate character (French Frigates Shoal). Of the 8 banks without reefs, 3 have cliffed volcanic stacks rising above sea-level near their centers, and 5 (no name, Frost, Brooks, Gambia, and 82-fathom bank) have neither bank reefs nor central islands. French Frigates Shoal is an intermediate type, since it has a cliffed central island and a reef on one side near the bank margin.

From data given in the Hawaiian Coast Pilot[2] and by Palmer[3], a more detailed account of the leeward islands is presented here.

THE LEEWARD SECTION OF THE HAWAIIAN RANGE

Nihoa, 140 miles WNW. of Kauai.—This island is a volcanic stack, $\frac{3}{4}$ mile long, $\frac{1}{4}$ mile wide, and 895 feet in maximum elevation. The stack rises from the southeastern end of a bank, 20 miles long

[1] W. M. Davis, "The Marginal Belts of the Coral Seas," *Amer. Jour. Sci.*, Vol. VI (1923), pp. 181–95. Also, *Proc. Nat. Acad. Sci.*, Vol. IX (1923), pp. 292–96; "The Coral Reef Problem," *Amer. Geog. Soc., Special Pub. No. 9*, (1928), pp. 182–86.

[2] "Coast Pilot Notes on the Hawaiian Islands," *U.S. Coast and Geodetic Survey* (1923), pp. 54–61.

[3] H. S. Palmer, "Geology of Kaula, Nihoa, Necker, and Gardiner Islands, and French Frigate Shoals," *B. P. Bishop Museum, Bull. 35* (1927).

and 11 miles wide, which slopes gradually to depths of 20 to 40 fathoms and then more rapidly to the deep ocean floor. Another bank, 3 miles to the southwest of the Nihoa bank, is 16 miles long by 10 miles wide, and is covered by from 10 to 30 fathoms of water.

Frost Shoal, 90 miles WNW. of Nihoa.—This bank "is about 14 miles long in an easterly direction," and is covered by from 12 to 63 fathoms of water.

Necker Island, 155 miles west of Nihoa.—Necker Island also is a volcanic stack composed of two principal parts joined by a narrow gap which rises only a few feet above sea-level. The highest point of the main section of the island has an elevation of 276 feet; that on the smaller section 156 feet. "At the eastern end of the main part of Necker is a low islet about 75 feet wide and 200 feet long. It is awash at high water and waves break over it continually." The island rises from a bank the extent of which is not known. The most probable limits are 15 miles northeast, 30 miles southeast, 5 miles southwest, and 7 miles northwest of Necker. "Except on the northeast side, the edge of the bank is abrupt." The depths of water over the bank are more than 14 fathoms.

French Frigates Shoal, 90 miles slightly south of west of Necker Island.—This is a crescent-shaped atoll about 17 miles from tip to tip. Midway between the points of the crescent is La Perouse Rock, a small stack 500 feet long, 80 feet wide; about 350 feet northwest of La Perouse Rock is another volcanic remnant about 10 feet high, 100 feet long, and 40 feet wide. No information about the surrounding bank is given.

Brooks Shoal, 30 miles WNW. of French Frigates Shoal.—This is an oblong bank 14 miles in a WNW. direction. At least 14 fathoms of water cover the bank.

Gardiner Island, 120 miles WNW. of French Frigates Shoal.—This consists of two small islands which, from the west or east, appear as a single island. The whole has a diameter of about 600 feet and a height of 170 feet. A bank with from 17 to 20 fathoms of water over it surrounds the stacks, and extends about 5 miles northwestward and southeastward, and from 10 to 12 miles southwestward.

Dowsett Reef, 133 miles south of west of Gardiner Island.—There is a bank extending from 5 to 10 miles off the reef and covered by from 10 to 20 fathoms of water.

Maro Reef, 10 miles west of Dowsett Reef.—This is a bank, from 2 to 7 miles wide, covered by from 10 to 30 fathoms of water.

Laysan Island, a coral island 65 miles south of west of Maro Reef.—A bank 6 miles wide, with depths of 14 to 60 fathoms of water over it, surrounds the reef.

Lisiansky Island, 117 miles WSW. of Laysan Island.—This is a coral island surrounded by a bank 5 or 6 miles wide, except on the southeast side where it extends for more than 30 miles. The depths of water over the bank are not given.

Pearl and Hermes Reefs, 155 miles WNW. of Lisiansky Island.—This is a large atoll 16 miles in an easterly direction and 9 miles wide. On the western side, the bottom drops off gradually to 35 fathoms, and then deepens very suddenly.

Gambia Bank, 35 miles WNW. of Pearl and Hermes Reef.—The dimensions of the bank are not given. The depths of water over it are more than 14 fathoms.

Midway Islands.—This is an atoll 6 miles in diameter which incloses two coral islands. No data regarding the surrounding bank are given.

Eighty-Two-Fathom Bank.—A bank with 82 fathoms of water over it has been reported 35 miles southwest of Midway Islands.

Johnston (Cornwallis Island).—This is surrounded by a bank 5 or 6 miles wide having from 5 to 10 fathoms of water over it.

The data presented in the foregoing pages show 11 distinct island groups in the leeward chain; these probably correspond to that number of simple or compound principal volcanoes which are similar in magnitude to those forming the windward section of the archipelago, and probably rose to similar or nearly similar heights above sea-level. Only 4 of the islands are lava-dome residuals, and even these tell us little of the majestic peaks from which they have been carved.

The depths of water in feet over these various banks are listed in Table I.

TABLE I

	Feet		Feet
Nihoa Bank	120–240	Dowsett Reef Bank	60–120
No-name bank	60–180	Maro Reef Bank	60–180
Frost Shoal Bank	72–368	Laysan Island Bank	84–360
Necker Bank	84	Lisiansky Island Bank	....
French Frigates Shoal Bank	....	Pearl and Hermes Reef Bank	210
Brooks Shoal Bank	84	Gambia Bank	84
Gardiner Island Bank	102–120	Midway Islands Bank	....
		Johnston Bank	30–60

The 14 platforms listed in the foregoing indicate the location of great volcanic mountains, part or all of which formerly projected above sea-level as do those of the windward section today. The structure and mode of development of these platforms has been explained in various ways.

The complete or almost complete destruction of the exposed portions of these mountains has been accomplished by long-continued marine and fluvial abrasion both at normal ocean-levels and at the lowered ocean-levels which existed during the Glacial epochs of the Pleistocene. Whether subsidence aided in the disappearance of the mountains is uncertain; Davis believes that such is the case, but the assumption is unnecessary. While certain of the mountains may have subsided to varous extents, there is no evidence that such a movement has affected the range as a whole; probably it has not taken place.

STRUCTURE OF THE SUBMARINE BANKS

The extent of erosion of the leeward domes plainly shows that the major volcanic activity on those islands ceased long before it did in the extinct mountains of the windward section. The cessation of volcanism on the older mountains of the latter group probably took place during the Pliocene or the early Pleistocene, though minor centers continued or became active at later periods. The principal vents of the leeward chain probably were finally sealed in the early or middle Tertiary.

Regarding the structure of the leeward submarine banks, Davis[1] states that they

[1] W. M. Davis, "The Marginal Belts of the Coral Seas," *Amer. Jour. Sci.*, Vol. VI (1923), pp. 181–95.

should not be regarded as shallow abrasional platforms of volcanic rock thinly veneered with organic and inorganic deposits, but as largely composed of coral-reef rock and lagoon-floor beds, built upon subsiding volcanic foundations with respect to normal ocean-levels in former non-Glacial period epochs, cut away by low-level abrasion during the Glacial epochs, and somewhat aggraded and imperfectly built up again by reefs in the present post-Glacial epoch.

In his latest contribution to the subject, the same authority writes[1] that

in view of the probability of subsidence, the banks, including those which do not bear reefs to-day, should be regarded as being only a part composed of abraded lava platforms and as largely composed of reef and lagoon limestones, built up to sea level during the subsidence of their foundations at times of favorable ocean temperatures and cut away, probably by low-level abrasion, at epochs of unfavorable temperatures.

An alternative view, which has been advanced by other investigators, is that many of these platforms in Hawaii and elsewhere have been developed by combined fluvial and marine abrasion about the shores of islands which have remained relatively stable for long periods of time. If this view be correct, the platforms are essentially wave-cut structures on which detrital accumulations are thin except along the outermost margins. Coral and other types of reefs which have grown up on these platforms are relatively thin deposits of calcareous material. In windward Hawaii, the islands of Kauai and Niihau present evidence favoring this hypothesis.

MARINE-ABRASION PLATFORM OF KAUAI

On the northern, eastern, and southern sides of Kauai is a wave-cut bench which has an average width on the northern and southern sides of 4 miles, and on the eastern side, where its erosion was greatly facilitated by the development of a large volcanic sink, a maximum width of 8 miles (Fig. 1). The bench was elevated by a tilting of the island along a northeast-southwest axis. Its inner margin now stands from 250 to more than 500 feet above sea-level. The western side of Kauai was submerged by the tilting so that the continuation of the platform, which originally stood at shallow depths below sea-level, is now at a depth of at least 300 feet below sea-level. Its

[1] W. M. Davis, "The Coral Reef Problem," *Amer. Geog. Soc., Special Pub., No. 9* (1928), pp. 182–86.

presence along the western side is indicated by a lava surface reached by certain wells located on the crescentic strand-plain bordering the cliffed highland of western and southwestern Kauai. The widths of the emerged section given in the foregoing do not represent the original widths, since, after emergence, a bench with cliffs ranging up to 250 feet in height has been cut into the platform (Fig. 2). The emergence was interrupted by short periods of still-stand, as is shown by the presence of minor wave-cut terraces eroded into the main bench. Except for occasional boulder beaches located along these minor terraces, no sedimentary deposits

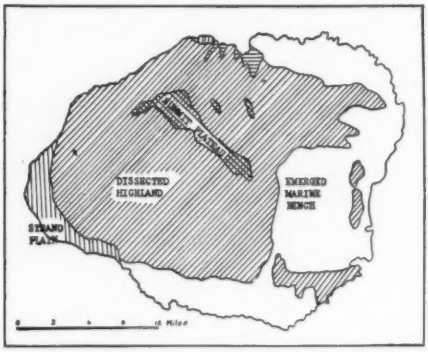

FIG. 1.—The physiographic subdivisions of the island of Kauai. The submerged continuation of the wave-cut bench exposed on the eastern side of the island lies below the reef and sediments of the strand plain.

FIG. 2.—The shoreward section of the emerged, wave-cut platform of northern Kauai. The cliffs which have been incised into this bench are about 250 feet high. A narrow, recently-emerged, wave-cut terrace is present at the base of the headlands.

are present on the platform; thus its structure is different than that postulated by Davis. According to the still-stand theory, however,

the sedimentary cover should be quite thin along the inner margin of a platform and thicker along the outermost part. As an island, such as Kauai, gradually emerged from the sea, the finer unconsolidated detritus would gradually be swept seaward and only the coarsest fragments would remain on the wave-cut surface. Thin sedimentary deposits may possibly have been present along the outer edge of the emerged surface, but these have since been destroyed by the marine abrasion along this outer edge. There is no evidence of the existence of pre-Pleistocene of inter-Glacial reefs about Kauai. The present reef, which is now extinct, is a thin layer of limestone rising from a recently cut bench submerged at shallow depths.

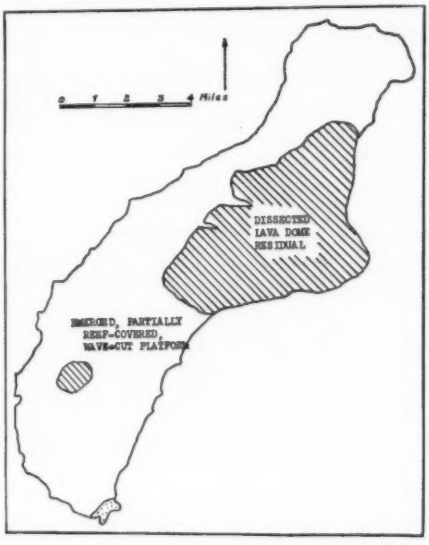

FIG. 3.—Physiographic subdivisions of the island of Niihau.

MARINE-ABRASION PLATFORM ON NIIHAU

On Niihau, a small island lying about 17 miles slightly south of west of Kauai, is a second, emerged, wave-cut bench. Bordering a small, cliffed, lava-dome residual on the northern, western, and southern sides is a plain of low relief which has a maximum elevation of about 50 feet at the base of the cliffs (Fig. 3). This plain averages 3.5 miles wide at its northern end, 1 mile wide opposite the dome-remnant, and 4 miles wide at its southern end. The plain has been formed by the elevation of a marine bench partially covered by a thin fringing reef which apparently does not exceed 100 feet in thickness (Fig. 4). Most of the plain is surfaced with basaltic and calcareous detritus, but locally lava or reef limestone is exposed. Some of the lava areas were islands in the pre-emergence sea; others

are flows and pyroclastics which have been erupted since the emergence took place. The contact between the limestone and the underlying lava-surface is visible in a few places. From the evidence presented, it appears that Niihau also remained stable for a long period of time during which the erosion of the marine platform took place. Upon this platform, the thin fringing reef grew; as the island was elevated the reef was gradually killed. The elevation was not accomplished by tilting of the island as on Kauai, nor was it as great

FIG. 4.—The emerged, reef-covered, wave-cut platform of western Niihau. The flat-topped eminence in the background is a volcanic residual which was an island in the pre-emergence sea.

or contemporaneous with the movement which affected the latter island. The platform is not found on the eastern side of Niihau; profound downfaulting has carried half of the dome below sea-level. The platform, of course, may be present about this submerged section.

Thus wide marine benches around two of the Hawaiian Islands show a structure different from that pictured by Davis. It is not unlikely that part or all of the submerged platforms in the leeward section of the archipelago are likewise wave-cut surfaces submerged below relatively shallow depths of water and covered with important sedimentary deposits only along their outer margins. Substantiation of this view, of course, is impossible in the absence of adequate evidence.

PETROLOGICAL ABSTRACTS AND REVIEWS

ALBERT JOHANNSEN

The Evolution of the Igneous Rocks. By N. L. BOWEN. Princeton University Press, 1928. Pp. 334; figs. 82.

This very welcome and valuable contribution to the physical chemistry of the igneous rocks is based on a course of lectures given to advanced students in the department of geology of Princeton University in 1927. In his Preface, Bowen says that the material of the lectures has here been considerably expanded, and that a "knowledge of the accumulated facts of Petrology, such as would be obtained in a general course, is assumed," but even this knowledge is insufficient unless the student has also at least a working knowledge of physical chemistry.

Bowen has omitted from the book all rock descriptions and classifications and other similar information, since he is convinced that "those sections of any new text which deal with the subjects mentioned are for the most part a profitless repetition of the similar sections of older texts." He says further: "The subject matter [of this text] is largely interpretative. It is an attempt to interpret the outstanding facts of igneous-rock series as a result of fractional crystallization."

The book is divided into two parts. In the first are given the phases of fractional crystallization of magmas to which data determined in the laboratory are fairly directly applicable. In the second part problems are discussed which require a relatively great amount of extrapolation from determined facts. Bowen's attitude toward the question of differentiation is shown by his statement: "Upon the question of the relative importance of fractional crystallization, as compared with other processes, in the derivation of igneous rocks, I can lay no claim to an open mind "; for he thinks that "to have an open mind on the question of fractional crystallization is itself a prejudice." He says, however, that "upon the relative importance of the various factors that may induce crystal fractionation, there is much room for an open mind."

The first chapter is devoted to a statement of the problem of differentiation. There are no specific discussions of different theories, and only a few are briefly touched upon in a general way. Bowen's thesis is that dif-

ferentiation is a continuous variation, so that there is no sharp demarcation of the rocks of one series from those of another. He follows von Cotta and Daly in believing the parent magma to have been of the composition of basalt, but he says that this assumption is not fundamental "in the sense that the whole system of the derivation of rock types by fractional crystallization would fall to the ground were the parental nature of basaltic magma disproved. Fractional crystallization would still remain the best explanation of the kind of relation shown between the various members of the rock series." He thinks that gradients of composition in a liquid, produced by the force of gravity, must be of very small magnitude; for while in any large mass, as in large permanent reservoirs of liquid in the depths of the earth, it is reasonable to suppose that they normally exhibit the composition gradient demanded by gravity, the amount of actual composition difference cannot be great enough to account for the differences observed in rock series. Two processes remain: liquid immiscibility and gaseous transfer. These are discussed in later chapters.

"Liquid Immiscibility in Silicate Magmas" is the title of the second chapter; and Bowen points out that experiments in the laboratory have shown that immiscible silicate magmas are all of highly specialized composition and that even in these the liquid fractions occur only at very high temperatures. He also points out that if unmixing ever occurred in a magma, evidence of it should appear in some of the igneous rocks, for example, as globules in a glassy lava. Furthermore, since the solidified rocks show many evidences of the separation of crystals and none as to the separation of liquid phases, he thinks the evidence conclusive against liquid immiscibility.

The third chapter takes up the general question of fractional crystallization. Bowen considers it proved that this causes differentiation not only by the concentration of certain minerals in the lower parts of an igneous mass but also by their associations and antipathies. That is, those minerals which belong to the same general period of crystallization tend to be associated, and those that belong to remote periods are, ordinarily, not associated. This association he also regards as proving that remelting of crystal material cannot be considered a sufficient cause. The factors which bring about differentiation during crystallization are the localization of the crystallization—for example, in the border of a body of magma—and the relative movement of crystals and liquid. In a cooling body of magma, crystallization begins at the borders of the mass; diffusion of substance is too slow a process to be of great importance. Convective circulation is more effective, but only the crystals attached to the cooling

wall are likely to grow from the moving liquid, since the suspended crystals will move with the circulating liquid. The most effective factors are relative movement of crystals and liquid, such as may take place by gravitative or deformative forces. The former is of most importance during the early stages of crystallization; the latter, during the middle and late stages.

Chapter iv, of thirty pages, deals with the "Crystallization in Silicate Systems." If the book is to be used as a text, it would have been highly desirable, from the standpoint of the average student, had it been twice as long.

Chapter v treats of the reaction between liquids and crystals in silicate systems, and is an expansion of Bowen's article in the *Journal of Geology* of 1922. Bowen believes that reaction is of much greater importance than the eutectic relation. The minerals appear in a definite sequence, just as they do in a eutectic series; but, in the former, they also disappear in a similar order, which they do not do in the latter. Further, he thinks that "the analogy with eutectic crystallization ends [at an early stage] for the simple reason that there is no eutectic." Each mineral tends always to change into a later member of the reaction series by reaction with the liquid.

The chapter on "The Fractional Crystallization of Basaltic Magmas," is an expansion of the theory first suggested by Darwin; on the basis of some observations of von Buch, that magmas differentiate by fractional crystallization and the settling out of crystals by gravity, or fractional crystallization and a squeezing out of the mother-liquor. Both of these were restated by Iddings and accepted by Becker, but they have been greatly developed by Bowen. He shows here how all normal subalkaline rocks could be developed from a basaltic magma by fractional crystallization.

In "The Liquid Lines of Descent and Variation Diagrams," he treats of different methods of plotting chemical compositions of associated igneous rocks, and of the changes in the lines of descent. He speaks of the general significance of variation diagrams and thinks that the characteristic curvilinear shapes are sufficient evidence to rule out the hypothesis that granitic and basaltic magmas are due to a splitting of a dioritic magma. Crystallization is thought to be the controlling factor.

The composition of the glassy rocks is found less variable than the granular. This is thought to be due to the "natural restriction of the possible compositions of the changing mother-liquors in a crystallization sequence [in these rocks] as compared with the wide range of possible com-

positions of the crystalline deposits from these liquids." He says: "The facts are destructive of any hypothesis which assumes the formation of the more extreme rock types by any process taking place in a wholly liquid magma, such as unmixing of liquids or transfer of materials from one part of the liquid to another by gases."

While magmas may incorporate considerable quantities of foreign inclusions, Bowen doubts whether enough foreign matter is ever present essentially to change the magma and produce a particular type of differentiate.

In the chapter on "Further Effects of Fractional Resorption," the statement is made that magnetite clusters are probably not due to synneusis, but are to be considered "a sort of pseudomorph of the resorbed mineral." As for volatile constituents, contrary to numerous other recent writers, he thinks that they play but a small part in igneous action as a whole, and are of little importance in the problem of igneous differentiation.

The last chapter is on "The Classification of Igneous Rocks" Bowen thinks that because the ratio of hares to foxes is 10 : 1 in one area and only 2 : 1 in another, a rock classification based on percentages of rock minerals is not fundamental, although he advocates the classification based on the ratio of the feldspars. The reviewer heartily agrees with him that the Rosenbusch-Zirkel system, the one most commonly used, is the natural one. Bowen says: "It takes the nature of the plagioclase, if present, as of fundamental importance. Since the nature of the plagioclase is an indication of the stage of development from an original magma, the use of that character is amply justified from the genetic point of view. It takes the nature of the colored constituent, whether olivine, pyroxene, hornblende or mica as a fundamental character also and, since this is again dependent upon the stage of development from an original magma, this feature of the classification is desirable. The same statement may be made of the use of the presence or absence of quartz and of other features of the classification." The reviewer objects only to the statement that the "quantitative element is relatively unimportant," for it is this lack of the quantitative feature that has made for the multiplicity of names.

The book is well printed on good paper, but the type is much too small. The pages appear crowded, and they are difficult to read.

REVIEWS

Brachiopod Morphology and Genera (Recent and Tertiary). By J. ALLAN THOMPSON. "New Zealand Board of Science and Art," Manual No. 7. Wellington: Government Printer, 1927. Pp. 338; pls. 2; text figs. 103. Obtainable from the Government Printer, Wellington, or the High Commissioner for New Zealand, The Strand, London. (17*s*., postage 6*d*.)

A very complete discussion of the brachiopod group is found in this manual. The results of recent study of living forms have added much to our knowledge of structure and ontogeny, and these newly discovered facts are here set forth. Thompson returns to the old view that the Telotremata developed from the Protremata, basing his conclusions on the fact that these groups have certain characters in common: a fibrous prismatic calcareous shell, articulation, and the presence of a delthyrium. He groups the orders under a subclass which he calls Pygocaulia, named from the fact that the pedicle develops from the caudal segment of the embryo. The Atremata and Neotremata are placed in the subclass Gastrocaulia, in which the pedicle develops from the ventral mantle lobe after the formation of the protegulum and during the free-swimming stage, and is subsequently protruded. On account of peculiarities in growth which resemble those of the Acrotretacea, the family Paterinidae is raised to a superfamily and is placed in the Neotremata. Because of the shell structure, the developing rudimentary articulation, the more or less rudimentary cardinal areas, the pseudodeltidia, and muscle scars like those of the Protremata, the Kutorginacea are placed in the Pygocaulia. *Rustella* adds calcareous matter to its shell, so it is included in the Pygocaulia. To receive the primitive superfamilies Kutorginacea and Rustellacea, a new order is erected, the Palaeotremata. The Siphonotretacea are referred to the Atremata on the basis of mixoperipheral growth in both valves. Two new subfamilies are erected, the Platidiinae to include *Amphithyris* and *Platidia;* and the Laqueinae to include *Laqueus* and *Pictothyris*.

Though one may not agree with many of Thompson's conclusions, yet he will find the book very valuable. The arrangement is excellent and the text figures very clear. The volume is indispensable to a paleontologist's library.

C. C. B.

Records of the Geological Survey of India. Vol. LXI, Part II. Calcutta: Government of India Central Publication Branch, 1928. Pp. 206; pls. 20.

A short paper by Cyril S. Fox gives the results of his recent discoveries in the Punjab Salt Range. Fox believes that the salt deposits are of Lower Cambrian age, and not of Eocene age, as current opinion holds. He accounts for the superposition of the salt by postulating extensive solution in the salt beds which has caused a sinking of blocks of the massive Paleozoics. The weight of the blocks has folded the remaining salt on to the surface of these Paleozoics, thus making the salt appear to be younger.

J. Coggin Brown discusses some miscellaneous deposits of iron ore in the Northern Shan states. The lower canine of a species of Conohyus is described by G. E. Pilgrim and N. K. N. Aiyengar. A. L. Coulson notes a new occurrence of leucopyrite. C. C. B.

Color Chart for Field Description of Sedimentary Rocks. By MARCUS I. GOLDMAN and H. E. MERWIN. Prepared under the auspices of the Division of Geology and Geography of the National Research Council, 1928.

The chart consists of two color plates, each 5 by 8 inches, with two like-sized pages of descriptive and explanatory text together with board covers. Plate I carries 52 variously colored blocks, each three-eighths of an inch square. Plate II carries 62 colored blocks. The colors and shades and their general arrangement are adapted, with some modifications and omissions, from *Color Standards and Color Nomenclature* (1912) by Robert Ridgway. Each color bears a symbol indicative of its spectrum position and its hue.

The object of the chart is the standardization of color description in geologic field work, particularly in the description of sedimentary rocks. The need for such standardization is generally acknowledged, and the matching of the color of a rock with that of one of the blocks of the chart and recording it in terms of its symbol, e.g., $21\frac{1}{2}d$ for the indefinite color name "straw yellow," would be of great value in the recording of notes. The authors of the chart and its descriptive text recommend that the original Ridgway publication be used in conjunction with, or in substitution for, this chart in laboratory and office work.

It is to be hoped that the use of the field chart may become general and that it may lead to a wider use of the elaborate Ridgway, or some other, standardized set of color symbols and thus promote the accuracy of color description in geologic literature. FREDERICK A. BURT